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A PRACTICAL THEORY OF VOUSSOIR ARCHES.

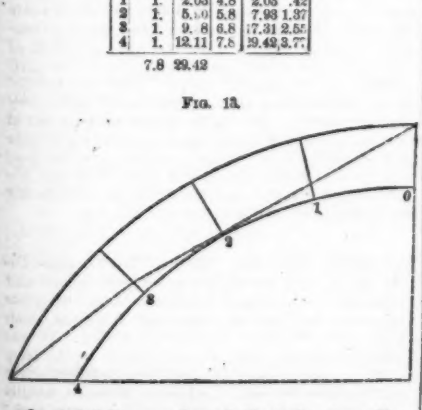
(Continued from October No., page 303.)

Eleventh Experiment.—Fig. 13. With this same Gothic arch a segmental circular arch was now made of 24.24in. span, and 7in. rise; the voussoir being as before 2. deep and 3.65 thick.

With 7.6 vs. on the summit, this arch *balanced;* the weight being placed on a small stick resting on the summit. With a greater weight rotation occurred on joints 0, 2 and 4, the crown falling.

	s.	m.	S.	M.	C.
	3.8	0.00	3.8	0 00	.00
1	1.	2.03	4.8	2.03	.42
2	1.	5.10	5.8	7.93	1.37
3	1.	9. 8	6.8	17.31	2.55
4	1.	12.11	7.8	29.42	3.77
		7.8	29.42		

Fig. 13.



On trial it was found that the true line of pressures passes .15 from the edges at joints 0, 4 and 2; giving the characteristics of both a maximum and a minimum thrust. We find

$$Q = \frac{7.8 \times 10.45}{8.85} = 9.21 \text{ vs.}$$

This horizontal thrust is greater than we have hitherto had, and probably accounts for the line of pressures retreating .05 further, in the arch ring, than we found for the Gothic arch. The construction is precisely similar to previous ones; the dotted line in Fig. 13 representing the line of pressures.

The ends of this arch required fastening tacks thrust into the board and pressing against voussoirs 4, .03 above the springing as in the first exp., with the Gothic, to prevent sliding. The thrust on joint 4 made an angle of 50° with the normal to that joint.

12*th Exp.*—With this arch resting on piers 3.63 wide, 5.8 high and 2. thick, each weighing 1.5 vs. the inner edge of pier being on a line with the springing, the arch balanced with .5 vs. on the summit.

We find, by constructing a line of pressures passing .15 from summit and the intrados at the third joint, that it cuts the base of pier .24 from its outer edge. Real arches have no mathematically plane joints, and therefore bear on the most elevated points.

This of itself may account for any *slight* discrepancies that we may meet with.

Some of Mr. Bland's experiments may now be tried, and they will be found to agree with the theory above ennunciated.

Thus in his first experiment, with a semi-circular arch of 24 in. span, the voussoirs being of wood, 2.5 deep and 4 thick, the arch being composed of 20 voussoirs; it stood with a weight equivalent to 2 vs. on the summit; falling with 2.5 vs.

The line of pressures passes very near the extrados at the crown and springing joints, and very near the intrados, half way between the crown and springing.

As in this experiment the weight probably bore on some extent of surface at the crown, and as the details of the method used to keep the bottom voussoirs from sliding are not given, and as besides the arch could not have been an exact semi-circular, if the voussoirs were 2 in. in *length* (along their centre line from middle to middle of joint) the construction evidently shows only an approximation to the truth. The same remark applies to some other of the experiments.

The second exp. with a segmental arch is equally illustrative of the theory advanced, as also Exp. 5. In Figs. 51, 52 and 53 of arches on low piers, we likewise have a proof of the theory in question.

Fig. 51 of Mr. Bland's treatise represents the semi-circular arch just mentioned, *balancing* on piers 7 in. high, the base measuring 4x4. The line of pressure passes near the summit, near the intrados at about 30° above the springing and near the outer edge of pier.

The lines of pressure in the arches, Figs. 52 and 53, pass through, or very near the summit and springing, and the outer edge of the piers.

Figs. 55 and 57, of Mr. Bland's treatise, represent Roman arches on piers, which, together with Figs. 54 and 56 of Gothic arches on piers, and Figs. 45 and 46 of Roman arches with weights on them (exps. with low piers), may be used to further illustrate Dr. Scheffler's theory.

In Chapter III of Mr. Bland's book are given numerous experiments of the effects of a horizontal force applied to the top of vertical piers built up of bricks of various heights and areas of base.

The reader will probably be surprised to find that, in the first 32 experiments given, if we regard the piers as *solid*, the actual horizontal forces exerted, to cause tumbling or rupture of some kind, was only three fourths, on an average, of the theoretical force required to cause *overturning* about an edge. The manner of rupture is not given by Mr. Bland, but it is evident especially from a consideration of his Fig. 26, that rupture was caused by *sliding* or sliding first and overturning afterwards.

In the few experiments of this kind by the writer, sliding usually occurred, even with brick piers; though overturning followed the sliding. Each brick seemed to have a different coefficient of friction, so that for these light piers, sliding often occurred some distance down from the top; though for blocks with the same angle of friction, the sliding ought to have occurred at the top.

It is true that in any case of overturning, the pier breaks along a diagonal and compresses at the edges, so as to cause leaning before overturning; but this cannot alone account for the discrepancy mentioned above, perhaps.

13*th Exp.* To form some idea of the action of mortar of different degrees of hardness, pieces of cloth .07 thick when not pressed, and .04 thick when pressed between two flat surfaces by the hands were put between the joints of the Gothic arch, (Fig. 11), each piece weighing .015 voussoir.

The span was then altered until the joints were all close, when it was found to be 14.57, the rise to the apex being 14.55. On placing a drawing-board by the side of this arch and tracing its contour curves, they were found to be very nearly arcs of circles, though not with their centres at the springing points. To locate them; measure horizontally from the springing points .32 towards the middle of the span, and then vertically downwards 0.1 to the centres, from which the arch may be drawn.

This arch balanced with 4.6 vs. at apex.; fell with 4.65 vs. The limiting lines to the curve of pressures, was found to be distant .3 = $\frac{1}{3}$ depth of joint from the contour curves, at its nearest approach to them.

This arch spread outwards upon the application of the weights, joint 2 being the point of rupture at the haunches; hence it is evident that if there had been a solid spandrel, or in this case, simply the pressure of the hands, to resist this

spreading, that the arch would not have fallen. The spandrel would have supplied horizontal forces in addition to the vertical ones due to its weight.

If the spandrel were not solidly built, at least up to joint 2, there would necessarily be derangement of the arch.

The curves of pressure were drawn in all the foregoing experiments, not taking into consideration the last mentioned derangement of the arch; which, in the last case especially, would have caused this curve to pass nearer the edges.

In fact, in most of the experiments, just before rotating, the edges alone seemed to be bearing. In the case of the simple Gothic, without cloth joints, when a sufficient weight was applied at the summit, the joint there, and joint 2, opened sensibly before the balancing weight was put on. The segmental arch flew out at the second joints, falling at the crown, only opening when near the balancing point.

Isolated weights applied at the summit, do not occur in practice, and it is hardly probable that a well-built viaduct, whose intrados is a segment of a circle, and of the proportions given in Fig. 9, with their joints only $\frac{1}{4}$ in. say, will spread appreciably after the mortar has well set; and this is necessarily a stronger form of arch than the semi-circular, elliptical, or hydrostatic, where the spandrel thrust is generally required to cause stability.

If the latter profiles are desired, let the depth of the voussoirs be increased towards the abutment, so as to keep the line of pressures within the proper limits of the arch ring, when the constructor will be assured of stability.

It certainly seems singular, that engineers should ever *recommend* an arch like the hydrostatic, which necessarily requires a very effective spandrel thrust to keep the arch from tumbling down.

The spandrels must in such cases be built with the same care used with the arch stones; thus increasing the *expense*, while really losing in *strength*.

14*th Exp.* In the joints of the same Gothic arch, pieces of soft woolen cloth .15 thick when not pressed, and .1 when pressed hard between two bricks by the hands, were next inserted, each piece of cloth weighing .027 voussoir. The span, when the joints were close, was found to be 15 in.; rise to apex, 14.63. The centres for describing the contour curves were 1.07 in. from the springing points measured horizontally towards the middle of span.

This arch balanced with 2.3 vs. on the apex.

Assuming this arch to preserve its figure, the curve of pressures passes about one fourth the depth of joint from the edges at its nearest approach to them.

This experiment gives us some idea of the effect of thick plastic mortar joints or of uncentreing an arch with fresh mortar joints.

15*th Exp.* A Gothic arch of about half the dimensions of the first given in *Exp.* 1 was cut out; really, before the arch we have just been considering.

It was not found to be symmetrical as to weight, one half weighing $\frac{1}{32}$ of the whole arch more then the other half. Still as arches in practice are unsymmetrical as to weight at least; it will be interesting to know, that assuming this arch to be symmetrical the curve of pressures passes .075 from the edges at the joints of rupture, more especially with weights at the apex.

All the preceding experiments were repeated with this arch and the same laws approximately established.

In the experiment with the cloth joints, the cloth was .05 thick not pressed; .04 when pressed hard by the hand. The curve of pressures was found to pass .1 from the edges at the joints of rupture, with a weight on the apex, and nearly so in the pier experiment with no weight on the apex.

16*th Exp.* Mr. Bland gives, (p 21,) an example of a Gothic arch of 24 in. span, voussoirs 2.5 deep, which fell of its own weight; though it was partly built of flat bricks, which accounts for its falling, for on making an arch of the above proportions it not only stood easily, but all the above principles were approximately established by it. The arch was not perfectly symmetrical as to weight, and was composed of 16 voussoirs; span 10.7 in.

The line of pressures passed within .075 of the edges at the joints of rupture.

The arch given by Mr. Bland, was probably not a true Gothic, or the joints did not fit along their whole extent; a sufficient hint to the constructor to exercise every care in these particulars in building.

It is to be regretted that in the experiments given by Mr. Bland, where backing was used, that he does not state its thick-

ness, except in the case of some experiments with models of bridges.

In the model of the Rochester bridge, Fig. 81, where the backing was carried up on a level with the summit of the arch ring, the line of pressures will be found by the method of Art. 8 to pass very near the edges at the summit, the springing and the outer edge of pier.

This experiment especially shows the error of passing a curve of pressures through the middle of the joints at the crown and springing, or within the middle third of the arch.

The bridge would have tumbled on either supposition. This bridge was 100 ft. span, and 15 ft. rise; the model having a span of 15 in. and a rise of 3.75 inches.

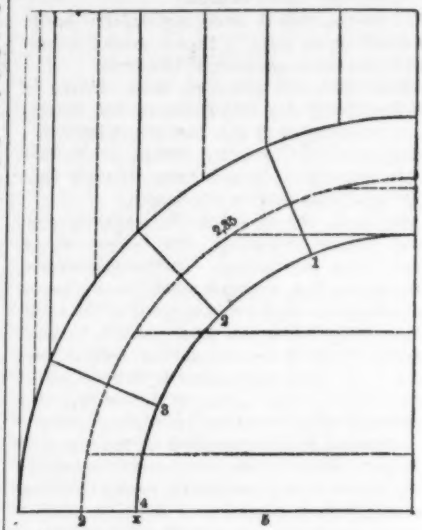
A series of extensive experiments on large arches, of stone or even wood, somewhat after the manner of these, is much to be desired as they would show us practically the effect of the compressibility of the materials upon the line of pressures.

Thus suppose stone or even wood arches of 10, 20, 30, 40, 50 and 100 feet spans to be cut out, and the balancing weights, at the crown, found. The distance that the line of pressures retreats from the edges follows, and we thus have practical data to work from, in designing similar arches; besides the law of that compressibility may be approximately found.

An example will now be given of a combination of the method used by Dr. Scheffler and that by the writer. Calling r, in Fig. 14, the radius of the extrados, r_1, that of the intrados and n the proportion of the circumference included by the voussoir, we have its content $= \frac{\pi(r^2 - r_1^2)}{n}$ for a thickness of 1. Now this is equal to $\Big[$the depth, $(r - r_1)$ $\times$ the *middle length* $\left(\frac{2\pi(r + r_1)}{n \times 2}\right)\Big]$ $= \frac{\pi(r_2 - r_1^2)}{n}$; hence measure the middle length and depth on a drawing, their product will give the required volume.

We now form the following table for Fig. 14, where the dimensions of the voussoir are given just below the dimensions of the corresponding surcharge. This manner of considering the voussoirs and surcharge separately is continued until in columns S and M, the quantities referring to the same joint are combined by the continued addition of the quantities in columns S and M separately.

FIG. 14.



	w	v	s	c	m	S	M	C
1	2.7 2.3	2 15 2.	5.79 4.7	1 38 1.18	.9 5.55	10.49	13.54	1.29
2	3.9 3.6	3 16 2.	7.17 4.7	3.88 3.36	27.82 15.79	22.36	57.15	2.55
3	4.8 3.35	5. 2.	7.55 4.7	5.77 5.18	43 56 23.64	34.61	124.35	3.59
4	6.8 3.35	7.2 3.	2.6 4 7	3 77 5.92	24.37 27·82	42.91	176.54	4.11
			42 91		176.54			

If the voussoirs are taken the same size, there is really no necessity of entering their dimensions; simply giving their common area in columns.

This manner of computing the surfaces (S) and their lever arms (C) is particularly applicable in the case of tunnel arches, which often have quite a depth of voussoir; as for example the Thames Tunnel, whose span is 14 feet, the depth of the arch ring being 3 feet.

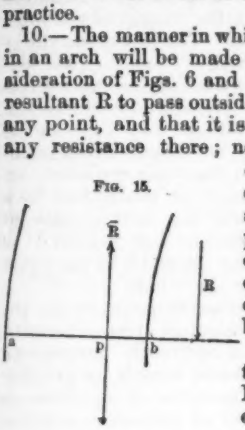
This method gives all the accuracy that is necessary in practice; expecially as arches are never symmetrical as to weight, and besides their spreading, if any, at the haunches requires an allowance to be made.

In experiments with arches with a backing, this method is especially applicable, particularly with full centre arches.

The decimals in the foregoing table are not carried out as far as they should be in practice.

10.—The manner in which rotation occurs in an arch will be made clear from a consideration of Figs. 6 and 15. Suppose the resultant R to pass outside the arch ring at any point, and that it is not opposed by any resistance there; next conceive two equal opposed forces, ‖ to R, to be applied at some point p (Fig. 15) of the joint. This evidently does not disturb the equilibrium.

Fig. 15.



We see, that there is a couple R$\overline{\text{R}}$ formed together with a force equal and ‖ to R acting in the direction of R at p; which last is resisted by the compressive reaction at the joint. The couple R, $\overline{\text{R}}$ can only be resisted by a couple; hence if there are tensile forces towards a, to be combined with the compressive reactions, a *resisting* couple may be formed of sufficient moment to maintain the equilibrium, and this is what usually happens in a solid arch of cast iron or concrete, etc.; but it is evident that if the joint can supply no tensile resistance, as in the case of a plane joint without mortar, or with mortar whose cohesive strength is null, then rotation must occur, as there is an unbalanced couple to produce it.

In fact (see Fig. 6) if the resultant R in any compressible arch, without tensile resistance at the joints, approaches nearer the edge than *its limiting* position, an unresisted couple is at once formed and overturns the arch.

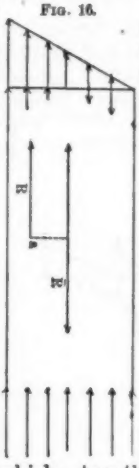
To consider the voussoir arch, whose joints can supply no tensile resistances, further, let us suppose first, the resultant R, (Fig. 6) to be in the centre of the joint; the forces f- - -, f'- - - may for a small joint be regarded as uniformly distributed. Suppose now the resultant R to move towards the edge b, slightly; there is still only *compression* on the joint, though its distribution is according to some unknown law. There is no couple formed until R has passed its limiting position, as is clearly shown by the preceding experiments; otherwise rotation would have occurred, which however did not happen.

In fact in moving the position of the resultant (Fig. 6) from the centre of the joint towards b, the stress becomes greater at b than at a; and some line $s\,s'$ will limit the values of the elementary forces f- - - - f'- - - -, representing them by arrows as in the figure.

We cannot, however, locate the line $s\,s'$ with our present knowledge, except in certain positions of R for solid arches, where actual tensile forces are brought into play; the usual theory for that case being as follows: Suppose the resultant R to be treated as in Fig. 15, the two equal opposed forces being supposed applied at the neutral axis or centre of gravity of the cross section of the beam.

The couple R $\overline{\text{R}}$ is resisted by the tensile and compressive resistances, acting respectively on either side of the neutral axis, as in the case of ordinary flexure of a beam. The remaining force, acting ‖ and in the direction of R, at the neutral axis, being decomposed into its elements, adds to some of the forces brought into play by the couple R $\overline{\text{R}}$ and subtracts from others.

Fig. 16.



Let us suppose the resultant R to approach the centre of gravity of the cross section; when it reaches a point a, which is $\frac{1}{8}$ the depth of beam from the centre of gravity, for a rectangular cross section, varying for other forms, there are no real tensile forces exerted at the joint (Fig. 16); and as a approaches nearer the centre of gravity the determination of the elementary forces at any point becomes uncertain.

In the solid arch, when R is farther from the centre of gravity than the point a, tensile forces are exerted about the farther edge, which, together with the compressive forces, form a couple, which transports the resultant R nearer the centre of gravity of the cross section.

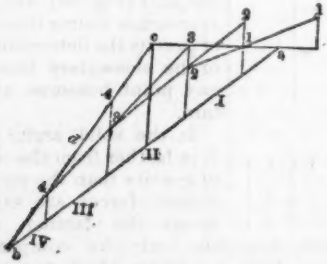
In the voussoir arch, whose joints oppose no tensile resistance, however, there is no resisting couple to effect this transfer of the resultant, and it is absurd to suppose the two equal opposed forces at the neutral axis, in which case the arch cannot be supposed to resist the couple

inevitably formed; with the same propriety might the two opposed forces be supposed, in the first instance, on the farther side of the arch ring; and yet certain authors seem to think that the line of pressures cannot pass outside the middle third of the arch ring without a couple being formed, and rupture ensuing, whereas our experiments have clearly proved that for the arches used this line of pressures passed on an average only $\frac{1}{3}$ the depth of joint from the edge at the joints of rupture, without rupture ensuing.

As the joints opened in many of the exps. before rotation occurred, it is evident that if the joint had been capable of offering tensile resistance, that it would have come into play, and prevented the opening; thus carrying the resultant nearer the centre and causing a more equal distribution of the resistance on the joint, than where the arch opposed no tensile resistance. Hence the utility of concrete arches, which can oppose such resistances, as also of solid metal and timber arches.

A good illustration of the agreement between algebraical formulæ and graphic construction, may be had from a consideration of two inclined rafters leaning against each other, one of which (supposed of very small cross-section) is represented by ab in Fig. 17.

Fig. 17



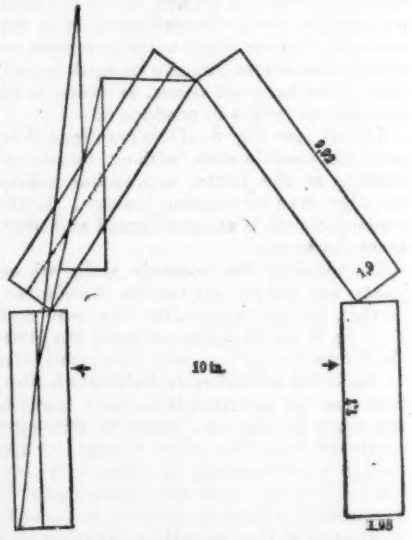
Reasoning as in Art. 2, we see that the thrust at the crown is horizontal; and if $\overline{c\,11}$ = weight of beam drawn through its centre of gravity, $\frac{1}{2}\,c\,a$ is the horizontal thrust.

Divide the length of the beam into any number of equal parts, four in the figure; combine as by the ordinary method, the horizontal thrust, at a, with the weight of the first division of the rafter, acting through its centre of gravity. Combine this resultant with the weight of the next division and so on. The last resultant $\overline{44}$ should pass through b and equal the thrust there, $\overline{ad}$ and act in the same direction. The other method of construction abopted in this article may likewise be used, particularly for many divisions of the rafter. The bending moment on joint I is the length $\overline{11}$, multiplied by a perpendicular, from the neutral axis at joint I, to its direction; that on joint II is $\overline{22}$ × perpendicular from II, to its direction and so on for the others.

Now if by the usual formulæ for an inclined beam, we calculate these moments, they will be found to exactly correspond to those found above, mostly by graphic construction. The *curve of equilibrium* $\overline{a\,1\,2\,3\,4\,b}$, as the curve of pressures is sometimes called, is, for a beam of uniform weight per unit of length, a parabola, whose vertex is at a, as is well known.

The component of any resultant, perpendicular to the beam, is the shearing force on the joint to which the resultant corresponds; the parallel components give the direct compressive force on the beam.

Fig. 18.



By algebraical formulæ, we know that the bending moment at I is equal to that

at III, that at a and b, being zero; also the shearing force at a equals that at b, at I, that at III; all of which we find by this partly graphic method.

Figure 18 represents two rafters 9.92 in length, 1.9 width (dimension in plane of paper) and 3.60 thick, leaning against each other at the top and against piers 7.7 high, 1.98 wide and 3.6 thick at their bottom edge, which is moved back 0.6 from the edge of the pier. The horizontal distance between the vertical piers is 10 in.; so that the feet of the rafters are 11.2 apart. Each rafter weighed 2.3 vs.; each pier 2. vs. The rafters and piers just balanced in this position.

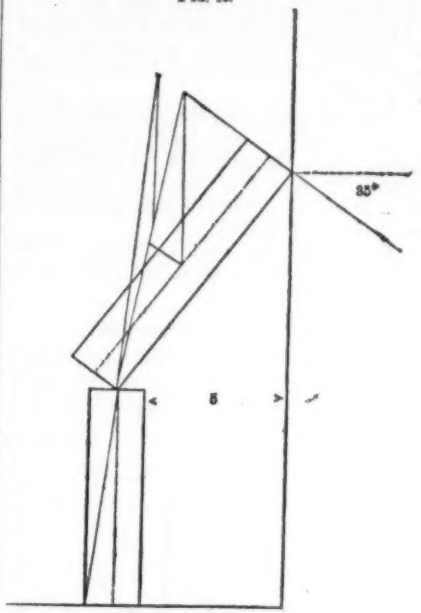
Reasoning as in Art. 2, we see that the thrust at the upper edges of contact of the rafters is horizontal; hence draw a vertical line through the centre of gravity of the rafter equal to its weight; the resultant on the lower edge of the rafter passes through this edge, which combined with the weight of the pier acting through its centre of gravity, gives the resultant thrust on the base of the pier. In this case it strikes twenty-two hundredths(.22) from its outer edge.

There is to be found in many standard works an erroneous theory of this case, which supposes half the weight of the two rafters to be suspended at the upper points of contact. If the reader will decompose this weight into its two components acting along the rafters, and then combine a component with the weight of the pier, he will find that the final resultant will pass .83 outside the base of the pier, and yet it stood well. The same thing may be seen on investigating Mr. Bland's exps. on rafters, p. 70. Until such palpable errors as we have noted along, are expunged from text books, the young engineer cannot be said to have a safe guide in the theory of his profession; and y^{e} old practical man will ever smile at the attempts to reconcile theory with practice.

The next Fig. (19.), represents a rafter and pier of the preceding experiment; the rafter leaning against a vertical rough plastered wall by its edge, the lower edge resting on the pier 1.03 back from its inner edge. This was the balancing position. The construction is as before explained in Art. 1, for Fig. 1.

After several trials, assuming as we found in the preceding experiment that the resultant strikes .22 from the outer edge of the base of pier, it was found that the direction of the thrust against the wall was inclined about 35° to the horizontal, which is about what we should imagine the angle of friction of the edge on the wall was. This proves the first proposition in Art. 1. Even if the thrust at the upper edge be assumed horizontal, it will be found that the final resultant passes outside the base of pier; hence, such an assumption is false. The construction (Fig. 19.) by extension, will also show that .32 v. of the rafter is sustained by the wall, 1.98 v. being supported by the pier; *i. e.* about one seventh of the weight of the rafter is upheld by the friction of the plastered wall.

Fig. 19.



On leaning a half arch against a wall, it was found to balance on higher piers than when the other half was placed against it.

11. It would be beyond the scope of this article, to follow Dr. Scheffler in the discussion of horizontal, as well as vertical forces applied to the arch, which however presents no difficulty. As all inclined forces can be resolved into vertical and horizontal components, it follows

that his discussion applies to any form of arch, solicited by forces inclined in any direction. A profile may be designed, by simply assuming first some form of arch deemed the best; then drawing its curve of pressures for the load passing through the middle of the joints at the crown and springing, and taking this curve as the centre line of the desired arch ring, when it will generally be found that the curve of pressures for this last arch will remain everywhere within the proper limits; a second trial being rarely, if ever needed, in practice.

Thus we find that the strongest form of arch, with a very high surcharge of masonry is the parabola. Dr. Scheffler found by a construction of this kind that the ellipse was the best form for an underground tunnel.

The simplicity and accuracy of Dr. Scheffler's method must commend it to practical engineers.

UNSYMMETRICAL ARCHES.

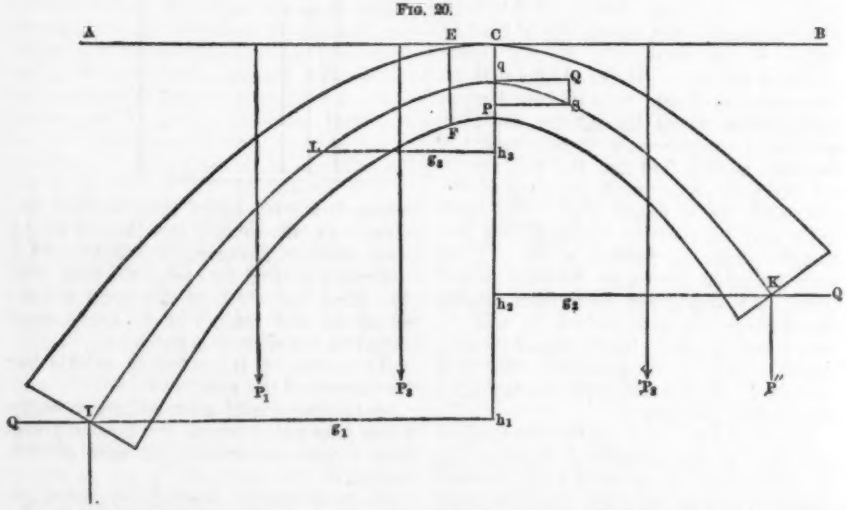
12. Dr. Scheffler demonstrates in this case, for incompressible voussoirs, what curve of pressures corresponds to the minimum of the thrust, and is therefore the true one. It would lead us too far here to enter into this discussion. The most usual case, being probably the only one met with in practice, furnishes this characteristic for the minimum thrust; *that it has two points of contact with the intrados and an intermediate point common with the extrados*, which is identical with what we have before found for symmetrical arches. This case includes that, where the points of meeting the intrados are at the springing.

There is a joint, EF (Fig. 20) generally near the crown at which the thrust is horizontal. Where the arch is only solicited by vertical forces, by compounding them with this thrust, as before, we find the resultants on every joint, and it is evident in this case that the horizontal thrust is the same all through the arch.

It is more convenient however, to find the inclined thrust at the crown and combine the partial weights with it, to find the resultant on each joint.

Problem: To find this inclined thrust and its point of application:

FIG. 20.



Let I, L, K be three points through which we wish to pass a curve of pressures (Fig. 20) $\overline{ACB}$ a horizontal line drawn through the highest point of the extrados, and let there be:

Q the horizontal thrust, *i. e.* the horizontal component of any one whatsoever of the pressures acting through I, L, K.;

P the vertical component of the pressure S at the crown joint, which will be considered positive, if it is directed upwards, as regards pressure from the right

part upon the left; in fact P may be regarded as a supporting force, when to the right of the joint E F, for if the arch only extended to C, P would be the weight that would be supported or resisted there; and so for any point of the arch to the right of E F.

Let q, be the vertical distance of the point of application of S below the horizontal $\overline{ACB}$; g_1, h_1; g_2, h_2; g_3, h_3, the horizontal and vertical co-ordinates of I, K and L as to the point C as the origin;

P^{I}, P^{II}, P^{III}, the vertical components of the pressures acting through I, K and L; P_1, P_2, P_3, the weights of the segments C I, CK, CL, with their loads;

p_1, p_2, p_3, the horizontal distances of the centres of gravity of these segments from the point C.

To abbreviate, let us put:

$g_1 - p_1 = a_1$ $\quad g_2 - p_2 = a_2$ $\quad g_3 - p_3 = a_3$
$h_1 - q = b_1$ $\quad h_2 - q = b_2$ $\quad h_3 - q = b_3$
$g_2 x g_3 = d_1$ $\quad g_1 x g_3 = d_2$ $\quad g_1 x g_2 = d_3$
$h_1 - h_3 = e_1$ $\quad h_1 - h_2 = e_2$ $\quad h_1 - h_3 = e_3$

We have:

$$P^{I} + P = P_1 \quad \ldots\ldots (1)$$
$$P^{II} - P = P_2 \quad \ldots\ldots (2)$$
$$a_1 P_1 - g_1 P = b_1 Q \quad \ldots\ldots (3)$$
$$a_2 P_2 \times g_2 P = b_2 Q \quad \ldots\ldots (4)$$
$$a_3 P_3 - g_3 P = b_3 Q \quad \ldots\ldots (5)$$

If the third given point L of the curve of pressures is upon the joint at the crown C, the value of q is known, and we have: $g_3 = o$, $h_3 = q$, $P_3 = O$. From eqs. (3) and (4) we find

$$P = \frac{a_1 b_2 P_1 - a_2 b_1 P_2}{g_1 b_2 + b_1 g_2} = \frac{a_1 e_1 P_1 - a_2 e_2 P_2}{e_2 d_2 - e_3 d_3} \quad \ldots (6)$$

$$Q = \frac{a_1 P_1 - g_1 P}{b_1} = \frac{a_1 d_1 P_1 + a_2 d_2 P_2}{e_2 d_2 - e_3 d_3} \quad \ldots\ldots (7)$$

If L is not upon the joint at the summit, we find*

$$P = \frac{a_1 e_1 P_1 - a_2 e_2 P_2 + a_3 e_3 P_3}{e_2 d_2 - e_3 d_3} \quad \ldots (8)$$

$$Q = \frac{a_1 d_1 P_1 + a_2 d_2 P_2 - a_3 d_3 P_3}{e_2 d_2 - e_3 d_3} \quad \ldots (9)$$

$$q = h_1 - \frac{a_1 P_1 - g_1 P}{Q} \quad \ldots\ldots (10)$$

* Add (4) and (3) and call the sum eq. (13); also subtract (5) from (3). Place the values of Q equal to each other in this last eq. and eq. (13); reducing, bearing in mind that $d_3 - d_2 = d_1$, $e_2 - e_3 = e_1$, &c., we find P as in eq. (8). Substitute this value of P just found in eq. (11) and deduce Q, which gives eq. (9). Eqs. (6) and (7) are only particular cases of eqs. (8), (9) and (10) when $P_3 = O$.

Example 1. Fig. 21 represents the same viaduct, before considered in Art. 8, with a load of 40 tons on 15 feet of length over divisions 2, 3 and 4, on one side of the arch only. Table 1 (Art. 8) refers to the right half of the arch: table 2 of the same article to the left side.

Let us pass a curve of pressures through the middle of the crown and through a point, on each springing joint, ⅓ depth joint above its lower edge.

We find from the drawing and tables

$g_1 = g_3 = 25.6$, $\quad b_1 = b_3 = 10.75$
$P_1 = 330$, $\quad p_1 = 15$, $\quad a_1 = 10.6$
$P_2 = 236$, $\quad p_2 = 16$, $\quad a_2 = 9.6$

From (6):

$$P = \frac{a_1 b_2 P_1 - a_2 b_1 P_2}{g_1 b_2 + b_1 g_2} = 24 \text{ cubic ft. of stone;}$$

from (7):

$$Q = \frac{a_1 P_1 - g_1 P}{b_1} = 268 \text{ cubic ft. of stone;}$$

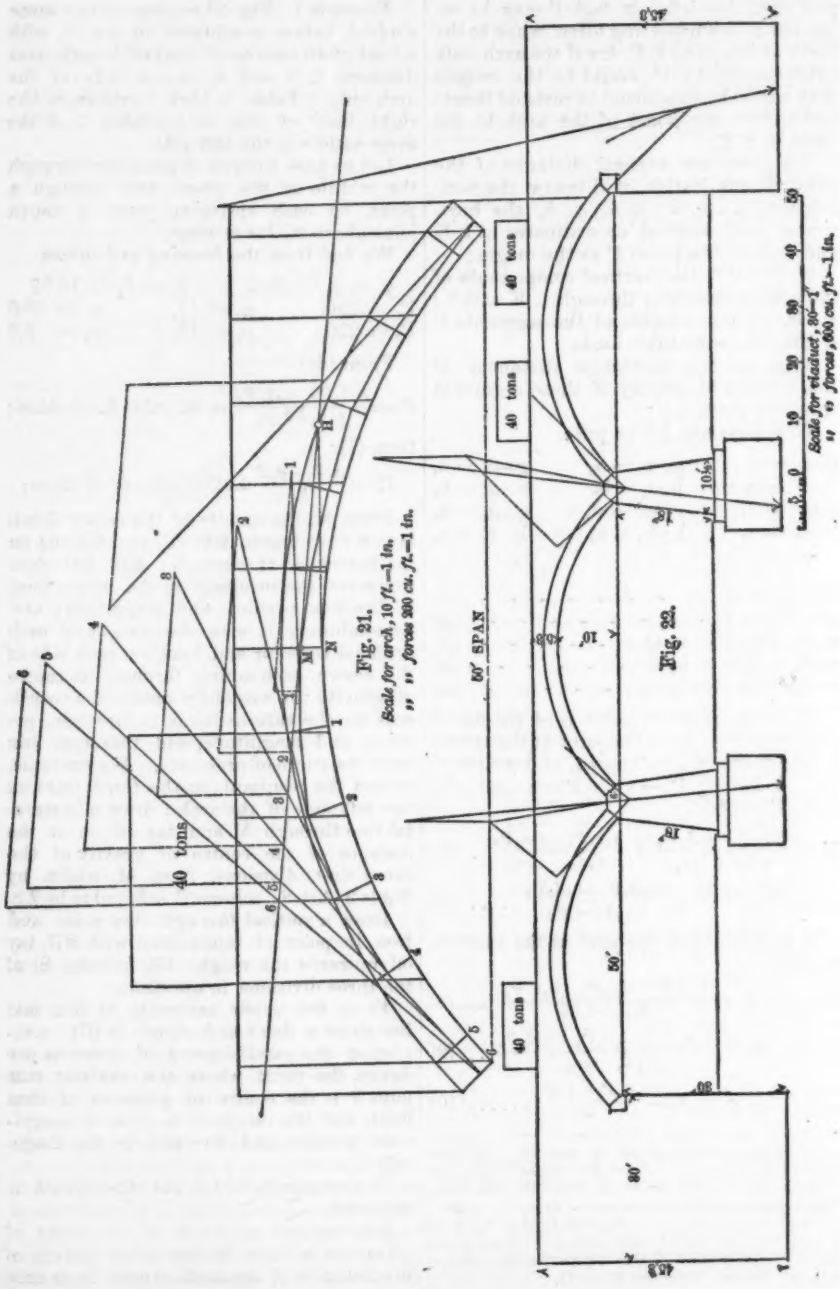
From M, the middle of the crown joint, lay off downwards $\overline{MN} = P$, also $\overline{NH} = Q$ on the horizontal through N; $\overline{MH}$ will then represent the resultant on the crown joint in direction position and magnitude; and by combining it with the weight of each artificial voussoir and load, on each side of the crown, each acting through its centre of gravity, we evidently obtain the resultants on the various joints in direction, position and magnitude, and therefore can trace the curve of pressures. For example, to find the resultant on the third joint on the left side of the arch: draw a horizontal line through M and lay off on it the distance of the centre of gravity of the three first divisions, from M, which by Table 2 (Art. 8), column C, is found to be 8.8.

Draw a vertical through this point and from its point of intersection with $\overline{MH}$, lay off upwards the weight 159 (column S) of the three divisions in question.

From the upper extremity of this last line draw a line $\parallel$ and equal to $\overline{MH}$; completing the parallelogram of forces as per figure, the point where the resultant cuts joint 3 is the centre of pressure of that joint, and the resultant is given in magnitude, position and direction by the diagonal.

The construction for the other joints is the same.

The nearest approach of the curve of pressures to the extrados is on joint 2, of the left side of the arch, where it is only


40 tons
40 tons
40 tons
40 tons
50' SPAN
Fig. 21.
Scale for arch, 10 ft.—1 in.
" " forces 200 cw. ft.—1 in.
Fig. 22.
Scale for elastic, 80—1'
" " forces, 600 cw. ft.—1 in.
50'
80'

three tenths (.3) of a foot (on a large scale drawing it was found to be .35) from the edge. The nearest approach to the intrados is at joints 3, 4 and 5 on the right, being only about .7 to .75 from the edges at those joints. Hence if we desire the curve of pressures, with this load, to remain in the middle third of the present arch ring, we must increase its depth about .6 ft making the arch stones 3 1 ft. in depth.

It will be interesting to compare some empirical formulæ with this result. Dr. Rankine gives * for the "depth of keystone for a single arch.

in feet $= \sqrt{\cdot 12 \times}$ radius at crown)"
$= \sqrt{.12 \times 36.25} = 2.1$.

Depth of keystone for an arch of a series, in feet $= \sqrt{.17 \times}$ radius at crown $= 2.5$.

Mr. J. C. Trautwine gives † for that span and rise 2.16 as the proper depth of keystone.

By interpolation from Dr. Scheffler's tables ‡ we find that he recommends in this case 3.5 ft. depth of keystone.

It must be remembered that when a locomotive passes rapidly over a bridge, that the principle of the least resistance can only apply approximately, as *it takes time* for molecular resistances to come into play; besides the shocks and concussions are the more damaging the smaller the bridge, hence while there is probably stability of the arch (Fig. 21) for a quiescent load of a 40-ton engine, it is not so certain for a moving load of that weight.

As the spandrels are not capable of exerting much resistance above joint 2, it seems that it would be advisable to increase the depth of keystone to three feet.

In fact while engineers have continued to increase the size of pieces in wood and iron bridges, as heavier engines were used, in some cases to double the size once used, yet they recommend for stone bridges the same depth of keystone that has been found to answer for road bridges built many years ago. We are indebted to Dr. Scheffler, now, for the means of completely investigating symmetrical or unsymmetrical arches, with any kind of loads, vertical or inclined, upon the hypothesis of incompressible voussoirs; besides we may be said at last to have got upon the right track of investigation as deduced from the principle of the least resistance; hence we should be no longer confined to purely empirical formulæ.

When we shall know the laws of elasticity, the theory may be regarded as complete for a statical load.

It looks probable, however, from a consideration of the experiments with the wooden arches, as well as cases in practice, that the theory for incompressible materials is not modified greatly; and it is more likely that severe shocks may have a greater influence in modifying that law, than the compressibility of the materials used. A considerable margin should always be left for these influences.

Example 2. A load of 13.3 tons was assumed on division, 3 on one side, and it was found that a curve of pressures could be drawn, for this eccentric load, within the inner third of the arch ring.

If the backing is raised higher, thus making the bridge weigh more, a rolling load will have less effect upon it; hence a less depth of keystone may be used. Other things the same, it is a simple question of economy, considering the approaches, whether to increase the height of surcharge above the arch ring, or the depth of the arch stones. The bridge considered could have the backing raised a foot higher with advantage.

Fig. 22 shows the effect of rolling loads in different positions, on the piers; the middle bay not being loaded but with its own weight, the end spans as per figure. The resultants at the springing joints we have before determined; combining the two on any pier with the weight of pier, according to the usual rule for three forces not intersecting in one point, we obtain the final resultants on the base of the piers. It is seen in Fig. 22, that in both cases, the resultant falls inside the base a sufficient quantity for a rock foundation, though probably not for a soft one.

It is seen from the figure that the 40 tons on both sides produce a more hurtful effect on the pier than a 40 ton load on one side only.

By combining the weight of abutment with the thrust on it, we find that the centre of pressure on the foundation course is sufficiently within the limits for most cases in practice.

The dotted line in the abutment gives the centres of pressure of all the forces act-

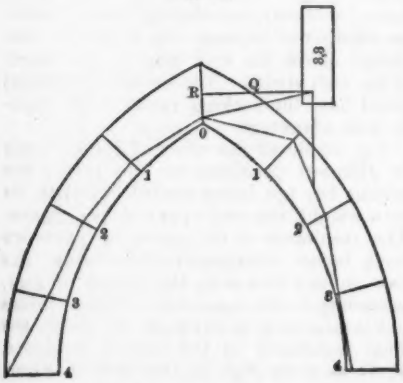
* "Civil Engineering," Art 290.
† "Engineer's Pocket-book," p 345.
‡ "Traite de la Stabilité," pp. 257, 277.

ing on each joint for the joints in question. For example, to find where this centre of pressure is on the springing line, produced, we combine the inclined resultant on the arch joint at the springing with the weight of the abutment above the springing line, acting through its centre of gravity. This resultant makes an angle with the vertical of only 23°, hence sliding on the springing course is not to be feared, if the abutment is solidly built. This centre of pressure must not be confounded with the points of greatest intensity of stress which includes the springing, but cannot be farther traced in the abutment composed of a number of stones.

We have considered the stability of this common form of viaduct under every point of view necessary in practice, and in the same manner can other forms of arch be investigated.

If in any arch the first trial curve passes on side the proper limits, mark the joint in its opposite the points of greatest departure and pass a curve through three points

Fig. 23.



thus found by the use of eqs. (8), (9) and (10). If the arch has stability at all, it will generally be found that this last curve drawn will remain in the proper limits; otherwise repeat the operation.

It would lead us too far to consider inclined forces, which are fully discussed by Dr. Schefflér and offer but little difficulty.

First Experiment. The Gothic arch given by Fig. 11 will now be considered with an unsymmetrical load. A stout needle was thrust into the second voussoir from the crown on the right side, in the direction of a vertical through its centre of gravity, as represented in Fig. 23. With a weight of 3.3 vs. on the top of the needle, the arch balanced; opening at summit and lower edge of joint 1 on the right. The voussoir to which the weight was added would have slid if pins had not been thrust into the edges of its joints, thus supplying a force analogous to friction, though not interfering at all with rotation.

We now form the following tables; the first being condensed from the one referring to Exp. 3, in Art. 9:

LEFT SIDE.

	S	C
1	1	1.70
2	2	3.19
3	3	4.39
4	4	5.26

RIGHT SIDE.

	S		M	S	M	
1	1.	1.7	1.7	1.	1 70	1.70
2	4.3	4 68	20.1	5 3	21.83	4.12
3	11.		6.79	6.3	28.61	4.54
4	1		7.88	7.3	36.49	5.
	7.3		36.49			

As the crown joint bore near the lower edge and the first joint on the right near its upper edge; try a curve of pressures passing .1 from those edges and .1 from the extrados on joint 4 on the left.

We find

$$g_1 = 8.9 \qquad g_2 = 3.9$$
$$a_1 = 3.64 \qquad a_2 = 2.2$$
$$b_1 = 12.2 \qquad b_2 = 0.65$$
$$P_1 = 4. \qquad P_2 = 1.0$$

By Eqs. (6) and (7) we find

$$P = \frac{3.64\times.65\times4 - 2.2\times12.2}{8.9\times.65+12.2\times3.9} = -.326$$

$$Q = \frac{3.64\times4+8.\quad.3}{12.2} = 1.43$$

P. is here minus, hence we lay it off upwards, then measuring Q to the right we get the resultant S at the crown from which the line of pressures may be drawn as in Example 1 of this article.

The line of pressures drawn with these values of P and Q passes .36 from the lower edge of joint 3 on the right. It should pass the same distance from the edges at joint 4 on the left, the crown and joints 1 and 3 on the right, to correspond to the maximum and the minimum of the thrust, hence this curve just found is not the true one.

In two more trials, it was found that the true line of pressures passed about .18 from the edges just mentioned, as drawn in Fig. 23.

Although the characteristics of the minimum and the maximum of the thrust are not demonstrated, the reader will perceive that there should be stability in this case as the line of pressures is inside the proper limits. The lower edge of the crown joint was imperfect, being the only imperfect edge in the arch, and this may account for the line of pressures retreating farther in the arch than for a load on the summit as before considered.

The thrust on joint 1, on the right, was inclined at an angle of 15° to the normal to that joint, which accounts for the sliding, as the joints were planed and across the grain.

2nd Experiment.—The segmented arch, Fig. 13 was next tried with the eccentric load.

A short needle was thrust in voussoir 2 on the left, in the direction of the vertical through its centre of gravity, as shown in Fig. 24: the arch balanced with 5.4 voussoirs on the top of this needle.

We form the following tables

RIGHT SIDE.

	s	m	S	M	C
1	1	2.03	1	2.03	2.03
2	1	5.40	2	7.93	3.96
3	1	4.78	3	17.31	5.77
4	1	12.11	4	2	

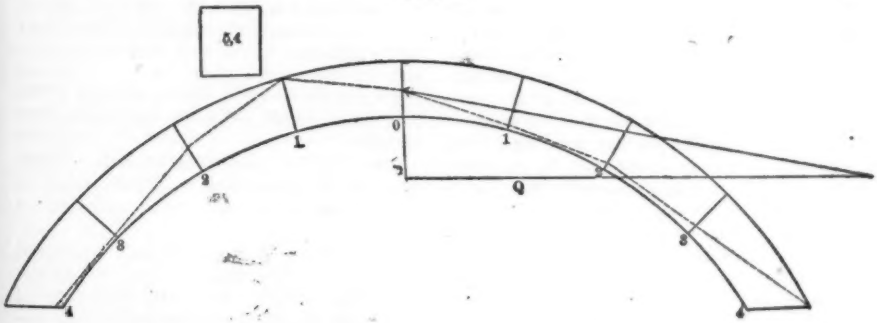
4 [illegible]

LEFT SIDE.

	S	M	S	M	C
1	1.	2.03	1.	2.03	2.03
2	6.4	37.76	7.4	39.79	5.38
3	1.	9.38	8.4	49.17	5.85
4	1.	12.11	9.4	61.28	6.52

[illegible] 61.28

FIG. 24.



The voussoir on which the weight was placed would have slid along its joints, but for pins being thrust into its edges in a manner that did not interfere with rotation.

The arch flew out at joint 2 on the right, hence a curve of pressures was tried passing .2 from the inner edge of this joint as also the middle of the crown, and .2 from the intrados at joint 4 on the left. This curve indicated the true curve more closely. A curve of pressures was next tried passing .2 distant from the intrados at joint 4 on the left and the extradosal edge at joints 1 on the left and 4 on the right. In this case we find from the drawing and the tables:

$g_1 = 12.32$ $g_2 = 4.14$ $g_3 = 14.17$
$a_1 = 5.80$ $a_2 = 2.21$ $a_3 = 6.8$

$h_1 = 9.$ $h_2 = 0.8$ $h_3 = 9.$
$P_1 = 9.4$ $P_2 = 1.0$ $P_3 = 4.$
$e_1 = 8.2$ $e_2 = 0$ $e_3 = 8.2$
$d_1 = 18.41$ $d_2 = 26.49$ $d_3 = 8.08$

From equations (8), (9) and (10) we obtain

$$P = \frac{5.8\times8.2\times9.4 - 6.8\times8.2\times4 + 2.21\times0\times1}{8.2\times26.49} = 1.03$$

$$Q = \frac{5.8\times18.41\times9.4 + 6.8\times8.08\times4 - 2.21\times26.49}{8.2\times26.49 - 0} = 5.36$$

$$q = 9 - \frac{5.8\times9.4 - 12.32\times1.03}{5.36} = 1.2$$

On constructing the curve of pressures with this data, we find that it passes .15 from the intrados at joint 2 on the right and of course .2 distant from the edges at joints 4, 1 and 4, as assumed; hence the

true curve will probably pass about .18 from these edges. This is nearly (.03 difference) what we obtained, for the limits from the edges of the line of pressures in the 11th Exp., Fig. 13. The thrust on joint 1 on the left is inclined 16°.5 to the normal to the joint, nearly what we found before. This sliding in this and the last experiment only occurred just before the balancing weight was applied; the line of pressures travelling down the crown joint as the weight was increased, until finally the direction of the pressure on joint 1 exceeded the complement of the angle of friction.

After patiently investigating all the preceding experiments, we can not but conclude that Dr. Scheffler's theory of the curve of pressures, viz., that it corresponds to the minimum thrust that is consistent with the physical properties of the materials, is proved and beautifully illustrated by them.

13. Analytical formulas for arches are founded upon this hypothesis*: that a curve drawn tangent to the resultant pressures on the joints, coincides, for all purposes of testing the stability of the arch, with the line of pressures of Dr. Scheffler.

Now it is evident in the first place that the above hypothesis can only be proved by innumerable graphic constructions; hence the latter method is the real foundation of the first, if the hypothesis is shown to be correct by the constructions. In the second place, the hypothesis is near enough in some cases as *e. g.*, our viaduct, Figs. 9, 10 and 21, but that it is not so in other cases may be seen by drawing the tangent curve to the resultants, in the case of the oval of the Neuilly bridge (Scheffler Fig. II.) about joints 6 and 7; the pointed arch, Fig. IV., at joints 4 and 5; as also the experiments with the Gothic arches of this article, where the tangent curve does not cut the springing joints at the true centres of pressure, and hence the true line of pressures would not have been given by the analytical formulas. In fact an arch may be perfectly stable, when this tangent curve passes outside of the arch ring. Dr. Scheffler handles this and other theories with gloves off. The graphic method is so simple, and so little liable to error, compared with the other, that constructors will probably prefer it in testing the stability of an arch. It must not be forgotten, though, that analysis has afforded us the proper form of arch for many particular kinds of load; though the graphic method will effect the same thing by assuming our arch, drawing a line of pressures through the middle of the crown and abutment joints and then taking this line for the centre of the arch. A second approximation will rarely be needed if the first form of arch is chosen with some discretion.

The graphic method is *general* and applies to any conceivable arch, loaded in any conceivable way, symmetrically or otherwise.

The theory of groined and cloistered arches, as well as domes, is treated by Dr. Scheffler, making use of the principle of the least resistance to ascertain their stability.

*Rankine's Civil Engineering, Art. 280.

COMBINATIOM BRIDGES FOR RAILROADS.

By J. O. PATTERSON, C. E.

Written for Van Nostrand's Magazine.

In advocating the adaptability and economy of the use of Combination Bridges on railways, the writer has been frequently met by the assertion of two objectionable features.

First.—That the difference of expansion from change of temperature in wood and iron causes such a serious loss of camber in hot weather that the bridge is in danger of falling below the horizontal line.

Second.—That the difference in cost between a bridge entirely constructed of iron and one of wood and iron combined is not sufficient to warrant the sacrifice of permanency due the iron structure.

Convinced by some experience of the practical economy and efficiency of combination bridges, the author has been led to examine the ground on which these alleged objections rest.

In regard to the first: the loss of camber, it is obvious that the expansion or contraction of the web members of a truss can not affect the camber, except to the infinitesimal

extent due the changes of depth of truss from that cause. Therefore we have only to consider the elongation of the bottom chord as tending to allow the bridge to sag. A moment's consideration of the nature of a truss shows this to be true. We have two chords taking the horizontal stresses and a system of triangles which take the place of the web of a solid girder, transmit the shearing stress to the abutments and maintain the chords fixed in the same relative position. Now if we increase the length of one of these chords, or rather spread each of the triangles of the web a little at the top, we force the truss to take a curved form. Because the long chord being prevented by the web from sliding on the short one they necessarily become parts of concentric circles, thus compensating for their difference of length. In a parabolic truss the want of parallelism in the chords does not affect the principle, but the increase of length in each panel would not be uniform but proportional to the depth of truss. Between 8000 and 9000 feet is the ordinary radius of the camber curve.

In order to ascertain the amount of variation of length which is likely to occur in the bottom chord, we will assume 150 degrees (*i. e.* from —30 deg. to x120 deg.) to be the maximum range of temperature for the section of country most actively engaged in the construction of railroads.

The expansion of wrought iron due 150 deg. increase of heat as given in the text books would equal 0.001 of the length of any bar of that material, but it is but fair to suppose that the drilling of the eye bars of a bridge chord (which determines their length) is done with the body of the bars at an average temperature of say 60 deg., therefore it is not the extreme variation of temperature which should determine the loss of camber, but the difference between that at which the bars are formed and the maximum.

However, as the top wooden chord is shortened by stress to a small extent, in the following calculations, we will consider the maximum range of 0.001, the length as affecting the bridge.

Taking, for example, a truss of 199′ 6″ clear span, and 24 ft. deep, say 14 panels of 14′ 3″ each on the Howe plan, with a camber of 7 in. Each panel of the top chord would be increased in length $\frac{6}{10}$ of an inch, and as there are 12 panels (the end posts and counter being omitted) the total increase in length of upper chord would be 7.2 in. The greatest possible longitudinal expansion of the lower chord equal 199′ 6″ $\times 0.001 = 2\frac{37}{100}$ in. $- 7.2'' - 2.37'' = 4.83''$ $= 4\frac{3}{4}$ in. camber remaining in bridge. The deflection under full moving load should be between $1\frac{1}{4}$ and $1\frac{1}{2}$ in., consequently there will remain $3\frac{1}{4}$ in. crown in the truss under the most unfavorable circumstances, which is certainly an ample margin for safety. As the camber and deflection are both proportionate to the span, there would be a proportionate margin in any length of truss.

The contraction of the chord in winter would simply have an opposite effect—increased camber; and while the bridge does not drop below the horizontal line and one end is free to move, can cause no excessive stress.

As regards the second objection, it seems to me that so long as the interest on the excess of cost of an iron over a combination bridge remains more than sufficient to pay for renewals of the latter, the former remains the most costly, or, to state it more conveniently, let c=first cost of combination bridge, and x=same for iron bridge, r cost of renewal in percentage per annum on first cost, and r'=legal or average rate of interest. Then we will say an iron bridge will only be economical when $x < \frac{C(r'+r)}{r'}$

In this case the greater original cost of the iron bridge may fairly be said to offset the inconvenience of the periodic renewals of the combination.

As an example, compare the cost of trusses 160 ft. in length, constructed on the two systems.

Such a bridge on combination plan, with timber planed to facilitate painting, and top chords housed or covered, can be built by any reliable firm, at present prices of material, for $40 per lineal foot.

We will suppose, to be on the side of safety, that the bridge will only be reliable for 10 years. An iron bridge by the same builder would not cost less than $70 per lineal foot, *vide* bids on the 25 Erie Railway bridges.

The two trusses will then stand as follows:

IRON.

First cost	$11,200
Interest 10 years at 6 per cent	6,720
Total cost at end of ten years	$17,92

COMBINATION.

First cost	$6,400
Interest 10 years at 6 per cent	3,840
52,000 ft. beam pine timber for renewals at $25	800
Labor on renewals at $5 per foot	800
Total cost at end of ten years	$11,840

The charge of $1,600 for renewals is = 0.025 per cent. per annum on original cost of combination truss, and applying our formula we have $\frac{C(r' + r)}{r'} = x =$ £9,066,66 and under this price we must build the iron bridge to obtain for it the merit of economy.

In the renewal of the combination bridge only the cost of timber has been figured, as the ironwork after ten years in it would certainly be as valuable as iron after the same service in the other truss.

GENERAL REMARKS.

If the end braces or posts of a combination bridge are of iron (about $1,00 per lin. ft. of truss will pay for Phœnix columns at end) and the top chord of timbers extending over not more than two panels, then the entire wooden portion of truss may be renewed piece by piece, without the employment of any false work.

A properly designed truss of wood and iron once carefully adjusted should require no more attention than one of iron. In fact, in the post combination no adjustment is possible, nor has it been found necessary. A change of length of probably $\frac{1}{64}$ of an inch in the vertical rods, or $\frac{1}{32}$ in the long diagonal with double intersection, can hardly be expected to disarrange the relation of parts of a truss to any hurtful extent.

Of the many forms of truss which have been adapted to the combination principle, the lightest, most elegant, and suitable of all seems to have been entirely neglected. I allude to the *inverted bowstring;* for a deck bridge nothing can be more simple and effective, and it is as readily adapted to a through bridge as the "Fink" or "Bollman." By varying the length of panel the eye bars may be kept of uniform length, the diagonal bracing necessary is extremely light, the posts have but a panel load to carry except towards the centre of span between the points at which the stresses change sign under a moving load where there is a slight excess to be borne. The top chord being subject to the maximum stress from end to end, would occasion serious loss of economy if of metal, but being timber, the fact is immaterial (as all attempts to reduce the amount of timber towards the ends of chords of that material to theoretic requirements have resulted in an expense of framing greater than the saving in timber), and furthermore, if there is any position about a bridge in which a cast-iron strut may be used with safety and economy, it is as a post in this style of truss. All these points considered, I think the inverted bowstring deserves a trial, at least.

Of the permanency of our iron bridges nothing has been said in this paper, as that question has been frequently raised and discussed; future experience alone will decide it; that some of them will fail in parts exposed to moisture but inaccessible to the paintbrush, is more than probable.

IS 772 FOOT-POUNDS THE TRUE DYNAMICAL EQUIVALENT OF ONE THERMAL UNIT.

By E. A. JACK, C. E.

Written for "Van Nostrand's Magazine."

Latent heat has been defined as the quantity of heat which disappears in producing changes other than elevation of temperature. Let us suppose the change to be that of volume, and convert it into foot pounds of energy, with air for an example.

The volume of 1 lb. of air at 32 deg. Fah., is 12.387 cubic feet, and it expands 0.0020276 of its volume, or 0.025 cubic feet for an increase in temperature of 1 deg. Fah., and in so doing exerts $2116.3 \times 0.025 = 5.29075$ foot pounds of energy.

Now the specific heat of air at constant pressure ($c\,p$)=0.238 of a thermal unit, and at constant volume ($c\,v$)=0.169 of a thermal unit. Hence $0.238 - 0.169 = 0.069$ is the latent heat of expansion or fraction of a thermal unit that has been converted into work of expansion.

And $\frac{52.9075}{0.069} = 766.8$ is the dynamical equivalent of one thermal unit for this process. This, substracted from Joule's equivalent, leaves $772 - 766.8 = 5.2$ foot-pounds, which may have been expended in producing work other than that of expansion.

LOCOMOTIVES FOR ASCENDING STEEP INCLINES WITH SHARP CURVES.

(Continued from October No., page 313.)

Every departure from this in an ascending direction, operates against the advancing power of the locomotive in two ways, viz., by diminishing the surface adhesion of the wheels and rails, and, on the other hand, proportionally adding to the weight to be raised or drawn up the incline. While the surface adhesion, on which the ability of the locomotive to advance depends, is diminished, the load it has to contend against is increased by bringing the force of gravity to act upon it, tending to drag it down the incline. The preceding observations embody the physical facts or principles, from which the best practical means of enabling locomotive trains to ascend inclines are to be educed. It is not *primarily* a question respecting increasing the power of a locomotive to enable it to draw a greater weight up an incline than on a level; for no amount of power can avail to effect the desired object, if the hold of the driving wheels on the rails be inadequate to keep the locomotive advancing, and hence it becomes one simply as to the best means of supplementing or compensating the diminished adhesion of the driving wheels on an incline, subjected at the same time, in its reduced state, to the direct opposing force of gravity.

To compensate for this loss of surface adhesion on inclines, recourse is generally had to coupling all the wheels, or as many as are practicable, to the driving wheels, or, in other words, to make use of the entire weight of the locomotive for adhesion. But it does not fulfil this end without incurring a disadvantage of a different kind, for increasing the number of coupled wheels of a locomotive beyond a certain limited extent, is open to serious objections, on account of the lateral frictional resistance encountered on curves by a series of coupled wheels connected in a longitudinal direction by rigid bars susceptible of little or no lateral motion.

The remedy to be sought, therefore, is to obtain an equivalent amount of surface adhesion by some other method which is free from this objection, and the design of these observations is to suggest one way in which this may be accomplished.

The framework of the locomotive and tender (which is rigid throughout) is supported on three axles so placed as to have as nearly as possible an equal pressure on each axle. The centre axle is of sufficient length to allow of transverse play through the axle boxes, and thus accommodate itself to curves of any degree of sharpness. The two end axles have not means for transverse play as the middle one, but have the boxes in which they run so arranged as to allow the axles always to point to the centre of the curve or curves on which the locomotive is travelling, with an arrangement of springs to cause them to return to their normal position on arriving at a straight portion of the line. The centre axle also has a certain amount of lateral play in its axle-box, but not so much as the two end ones. On each of these axles are two pair of wheels, one pair at each end placed close to each other, the wheels running on a pair of double rails. The outside wheels are the ordinary flanged ones now in use, while the inside pair have a concave surface running on corresponding convex rails. The motive power is obtained by three pair of cylinders, one pair for each axle. Each pair of cylinders are fitted on an independent framework resting on the axle, and supported at each end by wrought iron plates, between which the framework is capable of moving on friction rollers, etc., when force is exerted on it by the axles on the wheels entering upon curves, and thereby causing the pistons to act normally to the axles under all conditions.

So that we have, as it were, three independent locomotives with a boiler, tender, tank, etc., in common. Of course to supply sufficient steam for so many cylinders the locomotive must be of large dimensions; but that is no objection, as it is found that 50, 60, or even 80 tons of adhesion weight are required now-a-days for working cheaply constructed lines with heavy gradients and sharp curves.

In order to obtain as equal a pressure as possible on each axle, the boiler and

furnace are placed in the centre of the frame, and a coal bunker and water tank is placed at the ends. But these are mere matters of detail, and, of course, are subject to modification, depending on the nature and size of the locomotive. But the two great principles to be borne in mind are—1st, that the entire weight of the locomotive, &c., shall be available for adhesion; and 2nd, that there shall be no rigid couplings. As there are a double line of rails, the best gauge would be 5 feet 6 inches, which is the one used on the Indian Railways, and which is, if I mistake not, now considered to be the best, taking both economy of working and safety in travelling into account.

There are four points to be urged in favor of the adoption of a double pair of wheels on each axle and corresponding double rails:—

1st.—That the great pressure on the rails is relieved by doubling the points of support, which becomes a matter of the gravest importance when locomotives of upwards of 60 tons are used.

2d.—That the lateral frictional resistance resulting from the use of rigid coupling rods is got rid of, and

3d.—That additional safety and steadiness are obtained in running round sharp curves.

4th.—The surface adhesion is increased enormously, since the surface of the inner wheels and rails are made to fit exactly, and we have two surfaces in contact during the revolution of the wheels on the rails, instead of only two lines, which is the case with the coned wheels.

Against these advantages is to be balanced the additional outlay in the construction of the line; but, as the deterioration and wearing away of the rails is chiefly, if not altogether, caused by the driving wheels of a locomotive, these double rails should last double the time that a single rail does, supposing the same number of driving wheels run on the double rails as run on the single, so that the only loss is the interest of the extra outlay.

But what is it compared to the enormous savings effected by having steep gradients and sharp curves in lieu of expensive tunnels and viaducts. On curves allowance is made for lateral friction, by reducing the cross section of the inside rails.

I have still another plan to propose, but which is more suited for moderate gradients, such as are to be found at home, and which is applicable to the present system of locomotive trains. It consists in converting into assistant locomotives, worked by the pressure of the atmosphere, the tender, and any other vans or carriages of the train that may be deemed suitable for this purpose. The tender and carriages selected for this purpose would require to be furnished with a pair of driving wheels fitted up with the usual pistons and cylinders, having the usual apparatus of valves opening alternately to the atmosphere and to an eduction or vacuum tube. The latter to be carried below the middle of the connected carriages, having at the coupling of each carriage a flexible or yielding point, to adapt it to their independent movements, and terminating in exhausting cylinders, placed in the primary locomotive, and worked by the power of its engine, in addition to working its own driving wheels.

Without entering into further detail, it may be observed that the practical difficulties connected with this arrangement seem to be chiefly of a mechanical kind, relating to the joints of the vacuum tube, such as rendering them capable of being easily connected and disconnected, preserving their air-tight function and flexibility, and insuring them, under ordinary circumstances from being liable to injurious extension or compression amid the irregular movements of a train of loosely connected carriages having a certain amount of play between each. But in the present advanced state of the mechanical arts it cannot for a moment be regarded as being of a very formidable character.

As the pressure on any part of the atmospheric apparatus can never, under any circumstances, on account of imperfect vacuum, come up to 15 lbs. per square inch, there will be the less difficulty in making the joints at once sufficiently strong and flexible; while, for the same reason, general lightness may be consulted in the construction of every part of the arrangement.

The advantage of the plan just described is, that it permits the extension of locomotive power through the medium of atmospheric pressure, to any portion of

a train, thus rendering it assistant in the work of propulsion. But if it were desired not to carry it further than the tender, the most obvious and better way would be, instead of employing atmospheric pressure, to connect the tender by a steam pipe, having a strong flexible joint at the coupling, with the boiler of the locomotive for the supply of steam power to work the machinery of the tender.

Since this part of my paper was written in December 1862, Mr. Sturrock, the Superintendent of the Locomotive Department of the Great Northern Railway, has taken out a patent for working the tender by steam obtained from the boiler of the locomotive, and the results obtained by this improvement are exceedingly good. Thirty-three per cent. of excess of load, and 50 per cent. if the furnace is improved, has to be drawn by locomotives with their tenders thus fitted up.

With regard to the proposition for obtaining additional motive power by means of atmospheric pressure, I would wish to state that I bring it forward more as a suggestion than as a carefully worked out problem; of its practicability I have no doubt, provided that the exhaust is capable of maintaining a sufficient vacuum.

ON MORTAR.*

From "The Engineer."

In buildings and structures mortar is employed as the agent for causing the stones, bricks and other materials used in construction to adhere together, also to fill any crevices and irregularities in bedding them. Its use for these purposes is of the remotest antiquity; we read of slime being used in building the Tower of Babel, and asphalte in the construction of the walls of Babylon, and it is found from an analysis of mortar taken from the pyramids of Cheops that the Egptians employed lime and sand almost in exactly the same proportions that we now do; and even the careful directions given by Vitruvius in the fifteenth century were carried out until the more modern researches of Vicat.

The remarks in this paper will be confined to the treatment of mortar formed by the admixture of lime with sand and other ingredients; and as it is the author's opinion that a few facts obtained from actual practice are of much more value than any number of individual opinions which he might offer, he will, by the kind permission of Mr. George Fosbery Lyster,—member of this institution, and Engineer-in-chief to the Mersey Docks and Harbor Board—endeavor to base this paper on data obtained while studying the method carried out by that gentleman at Liverpool.

The limestone which has been here employed for the past forty years in carrying out the most extensive hydraulic works, is obtained from quarries situate in the Halkin Mountains, Flintshire, and is that ordinarily used in Lancashire, Cheshire, the West of England and Wales.

It is found from an analysis by Dr. Musprat of Liverpool to be composed of 75 per cent. of substances soluble in nitric and hydro-chloric acids, and 25 per cent. of those insoluble. The soluble substances are:—Carbonate of lime, 72.0 per cent.; carbonate of magnesia, 1.3 per cent.; proto-carbonate of iron, 1.0 per cent.; sulphide of iron, 1.0 per cent.; alkalies, 0.7 per cent. Those insoluble are:—Silicic acid, 20.0 per cent.; alumina, 3.5 per cent.; sesquioxide of iron, &c., 1.1 per cent.; water and carbonaceous matter, 0.4 per cent.

The limestone, in order to expel carbonic acid, is calcined in kilns, on plan oval 18 by 12 feet, and 20 feet in height from the fire-bars, which dimensions give a capacity of 3400 cubic feet. The interior is lined with fire-bricks, and the usual dome top is here dispensed with; three such kilns are built into one rectangular construction of rubble work, each of which is provided with a hoist for the purpose of lifting the limestone and fuel to the summit of the structure when filling the kiln. The charging is done in the following manner:—A few shavings are placed on the fire-bars, upon which is spread a layer of coke about six inches in thickness, limestone is then thrown in until a thickness

* Read before the Edinburgh and Leith Institution of Engineers, by Mr. Graham Smith.

of 1 foot, 10 inches or 2 feet is attained. This is followed by another layer of coke, and so on alternate layers of coke and stone until the top of the kiln is reached, the layers of stone gradually increasing in thickness to 2 feet 6 inches at the top, with the exception of the uppermost, which, owing to its being exposed to the atmosphere, is made only 9 or 12 inches. When completely charged, the shavings are lighted and the whole allowed to burn for six or seven days, as experience may direct, after which time not a trace of the coke is perceptible. The fire-bars are then withdrawn and the burnt lime raked out of the aperture thus formed on to the floor of an adjoining shed, where it is slaked with water, and produces a lime of moderate whiteness, after which, owing to the irregular size of the stones put into the kiln, it is occasionally found that some of the stones are not sufficiently burnt. When this happens they are picked out and reburnt, but by care in having the stones reduced to about the same size in the first instance this is of seldom occurence.

In burning lime care must always be taken not to reach too high a temperature, as, owing to the fluxing properties of the lime, the silica and alumina would combine and form a species of glass. The stones should also be broken to a comparatively small size, in order that the heat may more readily penetrate to their interior, and thus effect a saving in fuel. The amount of limestone put into the kiln is 113 tons or 1930 bushels, and the requisite amount of coke is 14½ tons. This produces 75 tons or 1170 bushels of burnt lime, which, with 15½ tons of water necessary to slake this quantity, yields 98 tons of slaked lime or 3411 bushels. From these quantities it will be seen that the slaked lime has nearly three times the volume of the burnt lime which produced it, and that its weight is nearly 9 per cent. more than that of the burnt lime and water together. Limestones, when calcined, produce rich limes, hydraulic limes, and cements. Rich limes are produced from stones consisting almost wholly of carbonate of lime, such as chalk. They slake freely, and during this process augment from two and a-half to three and a-half times in volume. These harden slowly in air and not at all in water, and the mortar formed from them is liable to be affected by changes in the atmosphere. Hydraulic lime is obtained from stones containing 15 per cent. to 30 per cent. of silicates and sometimes magnesia. These do not slake freely, give off little heat, and will harden slowly under water. Some stones, containing 40 per cent. to 60 per cent. of silicates, produce cements which do not slake, but which, when ground and mixed with water, will set in air or water in a few minutes. The agency to which mortars owe their power of setting is not generally understood, but it is commonly considered that this action in rich limes is due to the evaporation of water and the gradual absorption of carbonic acid from the atmosphere, thus forming a crystallized carbonate of lime. In hydraulic limes it is believed that the setting takes place from a chemical union of the lime with silica and alumina, thus forming an insoluble crystallized double silicate, without which mortars, placed in positions where air cannot penetrate, would never harden. The author therefore considers that the quantity of carbonic acid gas in the atmosphere being limited will to some extent account for the slow setting of rich limes; and as the atmosphere cannot penetrate to a great extent into thick walls and masses of concrete, it would be unadvisable to use for these purposes anything but hydraulic limes or cement, for the hardening of which the influence of the atmosphere is comparatively unimportant. From the analysis of the Halkin limestone, it will be seen that the components producing setting and indurating under water exist to the extent of 25 per cent., and being evenly distributed through its entire mass, produce a mortar most favorable to the formation of an insoluble crystallized double silicate. To obtain good mortar, as much depends on the character of the ingredients and the manner of mixing them as on the goodness of the lime itself. It does not necessarily follow that because a lime is good that the quality of the mortar will be good also. The best lime ever burnt would be spoiled by the custom common among some builders—to mix with it alluvial soil and rubbish taken from the foundation pits of intended buildings. The sand should be hard, sharp, gritty, and, for engineering purposes, not too fine; it should be perfectly free from all organic matter, and with no particular smell. Good sand for mortar may be rubbed between the hands without soiling them. The

water should also be free from all organic matter, and on this account should never be taken from stagnant ponds. The presence of salt in sand and water is not found to impair the ultimate strength of most mortars; nevertheless, it causes the work to "nitrate," or, as it is commonly termed, "saltpetre," which consists of white frothy blotches appearing on the face of the structure. It also renders the mortar liable to moisture, and for these reasons should never be present in mortar intended for architectural purposes, although for dock walls and sea-works it may generally be used with advantage and economy.

Sand is used to increase the resistance of mortar to crushing, to lessen the amount of skrinking, and to reduce the bulk of the most costly material, lime. Water is the agent by which a combination is effected, and, as sand does not increase in volume by moisture, it necessarily follows that no more of the aqueous element should be employed than is absolutely necessary to fill the interstices between the sand, and render the whole into a paste convenient for use, and the greater strictness with which this is adhered to, the more compact and durable will be the mortar. The mortar made from the Halkin lime is mostly employed on the Mersey Dock Estate in the construction of dock and river walls, for which purposes it is always mixed with salt water and sea-sand. The lime, within one to four days after being slaked, is taken to the mortar mills, which are cast iron circular pans 7 ft. in diameter, caused to revolve by suitable spur gearing at the rate of 20 revolutions a minute. In each pan are placed two rolling stones 4 ft. 6 in. in diameter. There are 14 such mills to each set of three kilns, which are driven by an engine of 50 indicated horse power, and it is generally calculated that one mill requires 3½ horse power to work it, as the mills are seldom all working at the same time. The engine before mentioned is found adequate to drive the mills, lift the stone and fuel to the top of the kilns, and to pump from an adjacent dock the required quantity of water for mixing the mortar. The pans of the mills are provided with false bottoms, in order that they may be replaced when worn out, the average life of these being about three months. In mixing the mortar the lime is first ground in the mills in a dry state for three minutes, the sand is then added, and after five minutes from the commencement the water is turned on, and as the necessary quantity is gauged by the tap, it is allowed to run the whole time, which, for the ordinary mortar, is about 30 minutes; the quantity made at each mill in this time is a quarter of a cubic yard. In some cases the amount is actually measured in order to ascertain if the men are making their full quantity. One man has to carry from an adjoining shed sufficient lime, sand and ashes to make five cubic yards of mortar in a day, for which he is paid 3s. 6d. The ordinary mortar used in the construction of rubble masonry for dock walls is mixed by volume in the following proportions: One slaked lime, two parts sand and one-third of a part smithy ashes. And the proportions for that used in brickwork are: One slaked lime, one sand and one smithy ashes. For the sake of convenience, in laying before you the experimental results obtained by these compositions, the author will term them respectively "masons' mortar" and "bricklayers' mortar." In practice the ingredients are not measured, as it is found that three average spades of lime, sand or ashes, are equivalent to one bushel. The mode of testing pursued was as follows: Bricks, the quality of which will be described in each individual case, were accurately cut to 4½ in. in width; these were in all cases thoroughly wetted, and bedded crosways, with a mortar joint $\frac{5}{16}$ in. thick and 4¼ in. by 4¼ in., giving a testing area of 18 sq. in. On the time arriving for testing, which, unless otherwise mentioned, was in every instance 168 days, or six lunar months, stirrups were passed round the ends of the bricks, two of these were attached to a beam, and on the remaining two was hung a bucket, into which perfectly dry sand was allowed to run from a hopper, the door of which was immediately closed when the joint parted; the bucket and sand were then weighed, and this was taken to be the breaking weight of the specimen. In order to ascertain the difference which would exist in practice from the employment of bricks of various texture, two qualities were experimented upon, namely, common bricks, similar although slightly harder than those known about London as "ordinary stocks," and fire-bricks, very hard and much the same as Staffordshire blue bricks. The "mason's mortar," with common bricks, broke with 496 lbs, with fire-bricks, 433 lbs. The "bricklayer's mortar," with common bricks, 610 lbs., with fire-bricks, 516 lbs. These are the average results of

three experiments in each instance, from which it would appear that soft porous bricks are preferable for work subjected in any way to a tensile strain. It being the author's impression that mortar when used in a structure would bear a greater test, owing to the compression caused by the weight of the superincumbent mass, some results were obtained by subjecting the samples, twenty-four hours after being bedded, to a pressure of 56 lbs., and following this up with an additional 56 lbs. every day, until 4 cwt. was placed upon each. The "mason's mortar" under these conditions, with common bricks, broke with 683 lbs.; with fire-bricks, 403 lbs. The "bricklayer's mortar," with common bricks, 372 lbs., with fire-bricks, 423 lbs. These are not average results, one experiment only having been made with each. The first instance is the only case in which the author's theory holds good, the remaining three cases being considerably below the respective averages of 433,610 lbs. before mentioned. This may be accounted for, as the author fears that in placing on the weights the mortar was disturbed after having partially set, in which case it will never bind together a second time. In the case of mortar remixed with water six days after the first mixing, it was found that with common bricks the "mason's mortar" broke with 432 lbs., against 496 lbs., obtained with the same mortar when first mixed; the "bricklayer's mortar" broke with 440 lbs., against 610 lbs, the advantage is thus shown of using mortar when first mixed.

The importance of the admixture of ashes with mortar to be atmospherically dried will be shown by the following results:—The bricklayer's mortar with common bricks after a lapse of eighty-four days broke with 570 lbs.; where sand was substituted in the place of ashes, that is, when the proportions were one slaked lime, two sand and no ashes, it only required 257 lbs. to tear assunder the bricks. These are the averages of three experiments. This is, no doubt, attributable to the ashes being porous; they thus allow greater facilities for the absorption of carbonic acid from the atmosphere. By testing with a Michell's lever cement testing machine, one of which is now before you, brickettes having a testing section of $1\frac{1}{2}$ by $1\frac{1}{2}$=2.25 square inches, the average result of three experiments was found to be 248 lbs., which will compare very favorably with the results obtained by Mr. Grant with Portland cement mixed in the proportion of three of sand to one of cement, which broke with an average of 270 lbs. From the foregoing it will be seen that nothing like these high results can be depended upon in actual practice, as the maximum breaking weight with bricks and mortar was 780 lbs., or 43.3 lbs. to the square inch, against 110 lbs., obtained by breaking brickettes. Although no experimental tests have been made with this mortar of any great age, still, from the pulling down of old work it may with confidence be asserted that it fully complies with the old Scotch rhyme:—

> "When a hundred years are past and gane,
> Then good mortar grows into stane."

On the Mersey Dock estate every stone and brick is properly bedded, jointed, and covered with mortar and "grout," which is simply the mortar reduced by water to a proper consistency. It is poured over the work, and penetrates into the body of the masonry, thus filling all cavities and assisting to keep the work moist during its progress, thereby producing an even settlement. It may be well to mention that this work is not done by contract, in which case the author considers so free a use of "grout" would not be advisable, as probably it would be made to perform imperfectly what ought to be done thoroughly with mortar. When using bricks they are in all cases moistened, as, if set dry or warm, the mortar would be robbed by absorption of the necessary moisture for its proper hardening. From practice it is found that a cubic yard of rubble work contains one-third and brickwork one-fourth of a cubic yard of mortar. The paper was concluded by a few remarks on the selentic patent process of mixing mortar, the practical manager of the company being present to explain the method, which, owing to his absence this evening, the author has thought it well to omit.

Since writing the foregoing paper the author has had opportunities for extending his researches, and with the permission of this meeting he will briefly mention one or two points. In "The Engineer" of December 3d, 1869, a very lucid description is given of the construction and working of Hoffman's annular kilns, the scientific arrangement and practical attainment of which it would be well to study previous to setting

up kilns for any purpose whatever. During a visit to the continent the author was invited to inspect one of these kilns near Boulogne, employed to burn bricks, and was supplied by the proprietor of the brick-field with the following particulars: The burning of 15,000 bricks requires three tons of coal, costing 90 francs, and the labor of two men one day, 10 francs, in all 100 francs, or £4, being equivalent to 5s. per thousand, which he considered was about half the ordinary cost. Whether the exact saving will reach this amount or not is a question to be decided by those familiar with the working details of brick manufacture; but the economy of the system is, in the author's opinion, beyond question; for when visiting some large lime-works in the neighborhood of Dorking, where two of these kilns were employed, the opinions of the continental brickmaker were fully endorsed by the manager. The lime here burnt was that commonly known as Dorking. It is slightly hydraulic, and is obtained by calcining the lower or grey chalks. It sometimes goes by the name of grey stone in London, where, being cheap, it is much in demand for ordinary building purposes, costing in the lump only 13s., and when ground 15s. per yard.

Although the first cost of these kilns is very great, still the before-mentioned results and opinions, together with the fact that the contractors for the Metropolitan and District Railways deemed it economical to set up kilns on this principle solely to burn brick for the construction of those railways, and removed them after their completion, will, in the author's opinion, fully sanction the large outlay where there is any amount of work to be got through.

The fall of the Northfleet chimney, and the many letters written to the editor of "The Engineer," on the question, are no doubt fresh im the memories of the members present; but it may be well to reproduce a portion of a letter written by one who states that he has had "some bitter experience in the erection of a shaft:" "If the precaution was taken in building these high chimneys to have a fire placed at the bottom of the cavity or in the shaft every night after the bricklayers had done their day's work, setting each night the work done the previous day, we should run less risks, and save the repetition of such dreadful calamities as the fall of the chimney at Northfleet."

The author, being of opinion that this advice was most misleading, and would, if carried out, be the cause of augmenting "such dreadful calamities," thought it well to reply, and although the text of his letter is embodied in this paper, he will quote a few lines, as the statements may be of value, having remained uncontradicted by the criticising public:

"The sun or heat will not set mortar; it simply dries it, and by so doing robs it of the n cessary amount of moisture required for its proper hardening, and thus materially reduces its resistance to crushing, as well as adhesive and cohesive strength. Mortar set in summer is not generally so good as that set in winter—of course, leaving frost out of the question. The expedient of placing a fire in the shaft of a chimney with the object of 'setting each night the work done the previous day' should never be resorted to. Mortar should never be hardened by heat; it would be equally justifiable to use warm bricks, which, it is needless to state, is contrary to sound engineering practice and the theory of mortar.—Nov., 1873."

We are told that this chimney was in design considerably more stable than many similar ones now standing; that it was constructed on a solid bed of chalk, with the best bricks, in the most approved manner; that the work was not pushed, and that there was not the slightest "scamping," all of which statements there is little reason to doubt; and to make things doubly sure, the mortar used in some of the work was composed of Dorking lime, sand, and Portland cement, which, in the author's opinion, had something to do with its failure, for lime and cement are very different in their action; the former hardens slowly, almost solely by the absorption of carbonic acid; the latter immediately (comparatively) by forming a crystalline double silicate of lime and alumina without the absorption of carbonic acid. The lime would certainly not attain any great hardness at the end of eight or ten days. If ground lime was used it would slake and expand some time after the cement had begun to set; consequently the mass would be disintegrated and little better than sand, unless the proportion of cement was very small, in which case the particles of set cement would be separated, and form a matrix round which the lime mortar could form a film as with sand; whether the lime was ground or

previously reduced to powder by slaking, it is questionable if the cement might not give an excess of alumina to the compound, and thus render it liable to contraction and the work to uneven settlement. Unfortunately, sufficient data are not at the author's disposal to enable him to give opinions with confidence, but those stated are to some extent borne out by the author's experiments, and by the fact that on the destruction of the chimney with gun-cotton, a portion, 5 feet in height, was blown away and every brick parted.

"Ah! you cannot make mortar or construct works as the Romans used to do," is an exclamation with which those engaged in construction are more or less familiar. Nevertheless, it is an erroneous conclusion, founded by the comparison of their work with the flimsy structures put up by speculative builders in the cheapest and worst possible manner. But when their works are compared with such as those of Mr. John Fowler, whose Metropolitan brickwork cost more to pull down than it did to erect, and their mortar with such as that employed by the engineer to the Mersey Harbor Board, their doings sink into insignificance; for this mortar, when six months old, sustains nearly the same tensile strain as the highest result of tests with Roman mortar taken from the South of France and recorded by Vicat, the average result of experiments with these two mortars being nearly two to one in favor of the former. And the author has been called upon to test and report on lime mortar which has at the age of six months sustained a tensile strain twice greater than that of the highest result above referred to, which was taken from the Tour Magna and had centuries of time to its advantage. Too much care cannot be exercised in ascertaining the proper proportions of lime, sand, and other ingredients. It is a peculiar circumstance that the better and more hydraulic a lime the less sand it will take up when made into mortar. Blue lias, among the most hydraulic and strongest natural limes to be found in England, like our artificial and natural cements, is completely spoiled by an excess of sand. To prove this, bricks were bedded in the manner previously described, with blue lias and common grey stone lime mortars, mixed in the proportion of one lime to four of sand, and at the age of three months required respectively 140 lbs. and 336 lbs. to tear them asunder. Had the proportions of lime to sand been one to two the results would in all probability been more than reversed. Blue lias is obtained in Somerset, Dorset, Glamorgan and Warwickshire. The following is an analysis, made by Professor Daniells, of blue lias found in the last mentioned county: Carbonate of lime, 87.2 per cent.; carbonate of magnesia, 1.4 per cent.; silica, 5.5 per cent.; oxide of iron, 0.5 per cent.; alumina 2.0 per cent.; bitumen and water, 3.4 per cent.; total, 100.0 per cent. The cost of this lime, delivered in London in December, 1873, was 25s. per ton when ground, in which state it is usually used, being somewhat troublesome to slake when in the lump, and unless the mortar is mixed in a mill, or thoroughly slaked, it is difficult to handle, as it will begin to set in ten or fifteen minutes—not a desirable property unless in the case of hydraulic construction, where it is invaluable; the mill keeping the mixture in motion, will do away with these very quick-setting properties without in the least damaging its ultimate strength or hydraulic qualities. The brickwork of the Metropolitan Railway was made with mortar composed of this lime, ground in a mill for from fifteen to twenty minutes; and it is only fair to the proprietors of the lime-works to say that in the destruction of the work only a short time after its erection, the bricks as often broke through themselves as through the mortar-joints.

In no material of construction is the ignorance of the "practical man" more manifest than in his treatment of mortar. He will often argue that since it is advisable to "sour" lime for the purpose of the interior decoration of houses, that therefore it should be so treated for all other work, forgetting, or not knowing, that by this means its indurating properties are much, if not quite impaired; but had he the sense to know and admit his ignorance, he would only prove himself to be little behind the most experienced and learned men on the subject, for sound conclusions cannot be formed without analyzing the properties of the lime, sand and other materials of which the mortar is composed. The study of the question in this manner yielding no immediate returns, is quite beneath the "practical" man's consideration.

Whether lime is to be used for mortar or concrete, it should, in the author's opinion, have time to slake before being put in place,

and if ground lias or other eminently hydraulic lime, a good practice is to spread it under a shed the night before it is intended for use, and so slake it by the moisture of the night air.

It must always be borne in mind that the strength of a chain is in its weakest link; so also the strength of brickwork subjected to tensile strains is in its mortar. In conclusion, the author would advocate a thorough study of details, as it is only by their mastery that one can hope to attain eminence or position in any profession or trade.

THE PHILOSOPHY OF WELDING.

By W. MATTIEU WILLIAMS, F. R. A. S., F. C. S.

From "Iron."

In the address of M. Jordan, President of the "Société des Ingenieurs" delivered at the annual meeting of the society in Paris, and reporter in IRON, pp. 650 and 679, a novel explanation of the welding of iron is offered. M. Jordan says that welding "is a phenomenon exactly similar" to the regelation of water, the phenomena of regelation being these, that if two or more pieces of ice at a temperature not lower than their melting point, or preferably at a temperature much higher than their melting point, be pressed together, the liquid water adhering to their melting surface becomes solid at the places of contact, and thus the two pieces are refrozen into one. M. Jordan very aptly illustrates the phenomena of regelation by the making of a snowball, telling us that this may be done "when snow is at a temperature not lower than 0. deg. centigrade, *i.e.*, the freezing point of water. Every man who has been a boy will confirm this, and remember that when the snow was very dry, and the temperature of the air below the freezing point, the snow-flakes would not cohere without the aid of much pressure and warmth from the hand, but that with sloppy snow during a thaw, he could make a hard icy snowball with ease. M. Jordan compares the making of the snowball by the children with the welding of the iron-ball by the puddler, maintains that the processes are identical, and applies Sir W. Thompson's rather recondite explanation of regelation to the cases of iron and platinum welding.

It appears to me that this explanation is fallacious, as the conditions of solidification in the two cases are not only by no means alike, but are diametrically opposite, the welding of both iron and platinum being effected at a temperature considerably below their melting point, while the primary condition for the cohesion of two pieces of ice by regelation is that they shall be exposed to a temperature above, or at least, not below, their melting point. In order that regelation should be analogous to welding, it should take place at a temperature far below the freezing point. Now it is well known that under such circumstances regelation does not and cannot occur, and therefore it differs essentially and primarily from welding.

If it had been discovered that two or more pieces of iron, while in a furnace, raised above their melting point and streaming into fusion, would cohere when pressed together, and that this cohesion resulted from the solidification of their liquid surfaces, in spite of the melting heat of the furnace, we should then have an analogy with the regelation of melting ice, and M. Jordan's conclusions would be justified. Regelation means the resolidifying of a liquid, or a special cohesion in spite of liquidity, welding means a special cohesion in spite of solidity, or apparent solidity. If M. Jordan had described them as examples of curiously opposite actions the comparison would have been more nearly correct. We might plausibly assume that, while the pressing together of two pieces of wet ice produces a solidification of the surface liquid, the pressing together of two pieces of heated iron has the opposite effect of momentarily liquefying the surfaces of contact, and thereby soldering them together. The plausibility of this explanation is increased by the fact that pressure develops heat, and thus the welding heat might, at the surface of contact, be momentarily raised to the fusing point, and then, on the removal of the pressure this liquid film might solidify and thus produce the welding cohesion. But even this theory is, in my opinion, too

learned. A far simpler explanation may be found, and we must never forget that when two or more explanations equally fit a given set of facts, the simplest is the best, and usually the true one.

In order to find a true analogy to welding we need go no further than the vulgar "sticking together" of two pieces of cobbler's wax, pitch, putty, or clay. These are in a viscous or semi-fluid condition, and they cohere by an action similar to the transfusion or intermingling and uniting of two liquids. Iron and platinum pass through a viscous or pasty stage on their way from the solid to the liquid states, and the temperature at which this pasty condition occurs is the welding heat. Other metals are not weldable, because they pass too suddenly from the solid to the liquid condition. Ice, although it fuses so slowly, in consequence of the great amount of heat rendered latent in the act of fusion, passes at once from the state of a brittle crystalline solid to that of a perfect liquid. It passes through no intermediate pasty stage, and therefore is not weldable, or does not cohere like iron, etc., at a temperature below its fusing point.

It is usual to cite only iron and platinum, or iron, platinum and gold as weldable substances, but this, I think, is not correct. Lead should be included as a weldable metal. The two halves of a newly-cut leaden bullet may be made to reunite by pressure, even when quite cold. This is obviously due to the softness or viscosity of this metal.

Outside of the metals there is a multitude of weldable substances. I may take glass as a typical example of these. Its weldability depends upon the viscosity it assumes at a bright red heat, and the glass maker largely uses this property. When he attaches the handle to a claret jug, or joins the stem of a wine-glass to its cup, he performs a true welding process.

The chief practical difficulty in welding iron arises from the fact that at the welding heat it is liable to oxidation, and the oxide of iron is not viscous like the metallic iron. To remedy this oxidation the workman uses sand, which combines with the oxide and forms a fusible silicate. If he is a good workman he does not depend upon the solidification of this film of silicate, as the adhesion thus obtained would be merely a soldering with brittle glass, and such work would readily separate when subject to vibratory violence. He therefore beats or squeezes the surfaces together with sufficient force to drive out from between them all the liquid silicate, and thus he secures a true annealing or actual union of pure metallic surfaces.

Cast iron or steel containing more than two per cent. of carbon cannot be welded. Why? I think I may venture to reply to this oft-repeated question by stating that the compound of iron with so much carbon is much more fusible than pure iron, or than steel with less carbon, and that it runs more suddenly or directly from the solid state into that of a liquid, and hence presents no workable range of weldable viscosity.

HYDRAULIC VALVES.*

From "Engineering."

ON VALVES SUITABLE FOR WORKING HYDRAULIC MACHINERY.

Since hydraulic power is now so extensively made use of in iron and steel works for a variety of purposes, any improvements in the machinery necessary to apply this power must be welcome to many members of this Institute, particularly if these improvements tend not only to facilitate the working, but also to reduce wear and tear and consequent frequent repairs, renewals and stoppages.

Making the joints of pipes and other stationary parts present few difficulties, the packings of the glands for rams and piston rods and the packings for pistons require more attention, because, if these are bad they will cause a greater amount of friction than is necessary to secure tightness, or they will be the constant source of leakage. The self-tightening leather collars and leather cups are up to the present time the only reliable packing for water under high pressure, but for pressures up to, say, 500 lbs. per square inch several other kinds of packing seem to answer well; but the parts to which this paper is

* Paper read before the Iron and Steel Institute at Barrow. By Mr. Robert Luthy.

particularly intended to draw your attention are the distributing valves or cocks required to work the different hydraulic apparatus. Some of these valves have to be of considerable size in order to give the proper speed to the machinery; for the tipping cylinders of Bessemer converters their ports are usually made proportionate to pipes of 2 inch bore, and for the centre-ladle-cranes they are even larger. The valves for the tipping cylinders have four ways, and those for cranes and hoists usually only three. As the water from the pumps is generally stored up in an accumulator, it is necessary that all the valves be so constructed that there can be no direct communication between the pressure and the exhaust sides in any position of the valves, *i. e.*, they must have sufficient "lap" to prevent loss of water. The valve faces have to be held together with sufficient pressure to keep the valves tight, and this causes considerable friction.

In earlier arrangements of Bessemer plant, taper brass cocks were almost exclusively used. The plugs of the cocks for the tipping cylinders having a medium diameter of 3 inches, were worked by a handwheel 24 inches in diameter, with intermediate gearing proportioned 1 to 4, thus making a total leverage of 1 to 32. To keep these cocks moderately tight, even when newly ground in, the plugs have to be screwed down so much that it takes a considerable pressure of both hands applied to the wheel to turn them. It is impossible to keep taper cocks tight for any length of time, owing to the difference in the space through which the top and bottom parts of the plug have to travel.

Valves have also been introduced in which the ports are disposed in a circle on a flat surface, and having a disc with recesses in the under side working radially upon the stationary face to bring the pressure and waste ports alternately into communication with the front or back end of the hydraulic cylinder. These valves are open to the same objection as all others having an oscillating or a revolving motion, with surfaces exposed to wear by friction at different distances from the centre of motion.

Brass slide valves of the usual D pattern, similar to steam engine slide valves, do very well for smaller sizes, and if their working surfaces are made of hard metal they last a considerable time; but for larger sizes the friction becomes so great, that in order to work them by hand, a very great leverage has to be employed, and this prevents the valves being opened or closed quickly enough.

Mitred plug valves are used in some places; they are opened or closed either by a screw cut on the spindle itself and working in a nut, or they are held on their faces by weighted levers which have to be raised for opening; separate valves have to be used for inlet and outlet, which makes the arrangement complicated and expensive, and it requires a great deal of room.

All the valves above described have metallic surfaces, and as the stationary face is generally in one piece with the body of the valve and with the connecting branches, considerable stoppages are caused in grinding or otherwise trueing up the surfaces from time to time, and when the faces are worn away, the principal body of the valve or cock has to be replaced at a considerable expense.

Valves have been introduced in which the peculiar properties of the leather collars for making hydraulic joints have been applied to the best advantage. The body of the valve is bored and cored out so as to form chambers communicating with the inlet and outlet pipes and with the pipes for the crane or press cylinder. The ram or slide is turned to fit the smaller bore of the valve, and has recesses turned in it to form annular passages for the water, and carries leather collars, the outer lips of which work against the bored part of the valve. Inside the valve there are also stationary leather collars, whose inner lips make the joint against the larger portions of the ram. The leathers and recesses of the valve and of the ram are so divided that in one position of the latter its larger portions are within the stationary leathers, and its movable leathers within the smaller portions of the valve, thus preventing any communication between any two adjoining chambers; in a second position of the ram or slide, its reduced portions come opposite the stationary leathers, and thus leave an annular passage for the water from the inlet chamber to the chamber in communication with the cylinder; in a third position, the communication between the inlet chamber and the cylinder is again closed, and the leather on the ram is drawn within the chamber communicating with the cylinder, and thus allows the water from the latter to pass into the outlet or waste chamber.

In valves for double-acting cylinders, the leathers and recesses are so arranged that one end of the cylinder is in communication with the pressure and the other end with the waste at the same time. The pressure on the ram in these valves is balanced in every direction, and in moving it, only the friction of the leathers has to be overcome. As some of the leathers work against the body of the valve, it is necessary that this, as well as the ram, are made of brass to obviate corrosion, which would materially increase the friction and cause the leathers, as well as the valve itself, to be quickly worn out The ram has also to be made in parts screwed together, in order to secure the moving leathers.

With the view of making the body of the valve of iron, removing all the friction from the same and limiting it to the ram, making all the leathers stationary and of uniform size, and the ram in one piece and of such construction that it limits its stroke, and that, after removing the top gland bolt nuts, the gland and all the leathers can be withdrawn at one operation with the ram and quickly replaced, the author of this paper has designed the valve represented by the two illustrations exhibited. One of these is a full-size drawing of a double-acting valve, suitable for working the tipping cylinder of a Bessemer converter, and adapted to take the place of the original four-way cock on the distributing box at present in use in most Bessemer works. On each side of the slide valve a mitre stop valve is introduced, so that the water can be shut off from the pressure and waste pipes, when the leathers in the valve or in the tipping cylinder have to be changed, or any repairs done in the connections between the main range and one vessel, without interfering with the working of the other vessels or the rest of the hydraulic machinery connected with the same main ranges of pipes. This provision has great advantages, and should be made for each separate apparatus.

The valve box is made of cast iron, and has branches for inlet, outlet, and for the pipes leading to the front and back end of the tipping cylinder. It is bored out uniformly down to the shoulder on which the brass ring supporting the leathers and the distance ferrules for the same, rest, and is fitted at each end with a gland through which the ram passes. The brass distance rings fit easily in the box, are bored to fit the ram, and turned on their ends to fit the concave and convex parts of the leathers as required. Their central portions are cored out larger to give sufficient passage for the water to pass all round the ram, and they have portholes to their sides to correspond with the branch openings in the box. The whole of the leathers and rings are firmly held in their places by the top gland, which is screwed down upon the common packing at the top. The ram, which is cast of hard bronze, is divided into a number of cylindrical pieces, connected by feathers or ribs of a cross section, forming passages for the water. The working portion of the ram is turned to an uniform diameter to fit inside the rings, and the r bs at the lower portion project a little, and form stops to limit the stroke of the ram by butting against the lower brass ring and the bottom of the lowest chamber when the ram is moved up or down. These projections serve also for withdrawing the whole of the rings and leathers with the ram when the gland bolt nuts are removed. The edges of the cylindrical portions are rounded off so that they may enter the leathers easily. When the ram is in its central position, the solid portions are within every leather collar, and the valve is thus divided into five compartments. The water under pressure is in the central or inlet chamber, and cannot pass into the chambers on each side of it which are in connection with the front and back-end of the tipping cylinder respectively, as the lips of the leather collars are turned towards the centre and make perfect joints with the ram as well as with the sides of the box The top and bottom chambers are connected by a passage at the side of the box with the outlet branch. When the ram is moved down into the position shown on the drawing, the water is admitted to the back of the cylinder through the openings formed between the ribs of the ram and the interior of the leather, at the same time a similar communication is established between the two upper chambers, letting the water from the front of the cylinder into the waste-pipe. When the ram is moved into its highest position, the pressure will be admitted to the front of the cylinder, and the back will be open to the waste pipe. As the cylindrical part of the ram enters the top and bottom leathers from the inner or open side, the lip is protected from being cut off by being held

back and secured in a groove, turned out of the brass ring, so that only about one-eighth part of an inch of the depth of the leather is free to make the joint with the ram. For the two inner leathers, this is not necessary, as the ram enters them from the back or round side; their lips are protected, however, from being bent in too much by the passing water, by lips in the central ring. A few small holes are drilled through the sides of the brass rings to admit the water to the inside of the leathers. To insure the brass rings being put into the box with their ports exactly opposite the corresponding ports in the box, a shallow groove is slotted down one side of the interior of the latter, and corresponding pieces to fit this groove are brazed to the outside of the brass rings. To prevent corrosion of the inside of the box it is coated with a thin layer of copper, deposited by galvanic process. With a single cranked lever of one to twelve, a lad can work the valve with great ease. Where there is very little pressure in the waste-pipes, it is not necessary to carry the ram through the bottom of the valve, as shown on the drawing, a slight back pressure not being able to move the ram upwards, by overcoming the friction of the leathers and the weight of the ram.

The second drawing shows a smaller and single-acting valve, fitted to an ingot crane. The water enters the top chamber; the central chamber is in connection with the crane, and the lower chamber with the waste-pipe. Part of the ram is here shown simply turned smaller for the passage of the water to the cylinder; the lower passage in the ram, however, is again shown with ribs of a cruciform section and the projection stops.

It will be observed that there is a leather-cup instead of a collar at the bottom of this valve as for ingot cranes or reversing gear cylinders, where the load has never to stand in a fixed position for any length of time, a good fit of the brass rings on the ram is sufficient to make that joint.

Many of these valves have already been applied to converters, centre-ladle cranes, lifts, reversing gear for rail mills, and presses for the manufacture of tuyeres for converters, and they all give great satisfaction. The leathers last a very long time, and if a valve has to be examined, or fresh leathers put in, it can be done in a few minutes.

HEAT AND ITS RELATION TO CONSTRUCTION.

From "The Building News."

Heat plays an important part in the economy of construction, and yet its effects are generally unheeded. Light and sound are readily discoverable by our eyes and ears, and therefore have received some attention on the part of architects and others interested in public assembly rooms and halls. On the contrary, heat is a condition not so palpably perceived; and gradations of heat are still less evident, therefore we are dependent, to a great extent, on the aids which thermometry affords. We are not concerned here in discussing the theories of heat, whether it be considered as a subtile form of matter, or caloric, as the "emission" theorists maintained, or whether it be simply the undulation of an imponderable elastic ether pervading space, and which physicists have now called the "Dynamical theory," or a "mode of motion." The able investigations of Drs. Tyndall and Joule, and others have shown "heat" and "power" to be convertible terms. The effects of friction, percussion, chemical action, all tend to establish the vibratory nature of heat, and to place it upon as secure a footing as the undulatory theory of light.

We propose here to indicate some of the common effects of heat in construction, and to show the disarrangements that may take place by great changes of temperature upon materials of different kinds, densities, and degrees of conductivity. As buildings are seldom composed of homogeneous substances of equable rates of expansion or contraction, it becomes a matter of some interest to consider what antagonistic forces are called into exercise by the combination of iron, stones, timber, &c., which are usually rigidly connected with each other, and how far these forces may, in course of time, or during a fire, impair the efficiency of construction, or the stability of the structure.

The expansion of metals is one of the most

serious questions connected with structures, and is often instrumental in dislocating bearing parts of a building, and weakening the entire fabric. We have latterly recorded in these pages several instances in which iron employed in girders and columns, both cast and wrought, has aided rather than averted the destructive action of fire and heat. In large warehouses in which iron girders form a complete network or frame within the brick or stone shell, the effect of any combustible material taking fire is to immediately cause such an expansion and pushing out of the walls that this disturbance alone becomes more thoroughly destructive than the ultimate power of the flames. The alternate action on such a build ng is first to push asunder the walls, and thereby di locate all bearings, and then the same girdering or framework, becoming red hot, bends itself under the weight of floors or roofs, and either draws together again the walls, or what is most commonly the case, leaves its bearings and falls bodily inwards, to the total destruction of all internal parts. It is this double action which takes place in a fire that places iron in the unenviable position of a destructive agent, rather than as a resisting one. It is somewhat surprising that architects and engineers so frequently neglect this expansibility of metal in girders, ribs, columns, &c., and provide no means for their free movement. Sometimes, it is true, the bearings of long girders in bridges are made of sufficient depth to allow for this increase of length; but even in these cases the mere weight of iron and superincumbent loads upon the points of support render the intended result nugatory, the weight of the iron girder alone often creating so much friction on the bearing surfaces as to overcome the rigidity of the supporting piers or walls, or the cohesion of mortar at certain points. This immovability of the ends of iron girders and joists is often increased by their being clenched or fixed by the weight of wall above, which often improperly is allowed to bear upon the top flanges.

To obviate this, engineers have contrived movable bearings more or less effective. One simple method we would suggest. Let each template be of cast iron of sufficient substance and bearing surface, and let it be placed upon an under template of stone or metal, the surfaces being either left smooth simply or brought into contact by a friction roller of small diameter, and of the length of the bearing surface. By this means free dilatation could take place, provided, of course, the ends of girders are left a free space of sufficient distance. No weight should be allowed to rest upon the ends of these beams, but in all cases the bearings should be free all round, and may be made as cast-iron sockets, built into the wall, or standing out independently.

The linear expansion a bar of iron undergoes when heated from the freezing to the boiling point, or from 32 deg. to 212 deg. Fahrenheit, is about one 812th of its length; at higher temperatures the elongation becomes more rapid. Thus the progressive dilatation of wrought iron, as determined by Daniell's pyrometer, allowing one million parts at 62 deg. is as follows:

At 212°.	At 662°.	At fusing point.
1,000,984	1,004,483	1,018,378

Cast iron is rather less.

It may be mentioned here that the expansions of volume and surface are calculated by taking the linear expansion as the unit, following a geometrical law, thus the superficial expansion is twice the linear; and the cubic expansion three times the linear.

These figures show how sensible a change takes place when iron undergoes an ordinary variation of temperature; and it may be said that in all ordinary cases of building this change is quite sufficient to cause serious disruptions of parts. Thus a bar or beam of even 10 feet long and subject to an ordinary change of temperature, say from 32 deg. to 180 deg., will elongate more than $\frac{1}{8}$th of an inch—a sufficient modicum to cause fracture to stonework, to snap the thread of a screw, or to endanger a bridge floor or roof truss. When we think of lengths ten and even a hundred times this dimension, the danger of uncompensated expansion or contraction is increased a thousand-fold. In ordinary cases the margin of safety is really dependent upon the amount of flexibility or elasticity of the parts of a building connected with iron, or to imperfection of joints; yet we should not rest satisfied with such presumptive security.

It would appear that the most promising mode of using iron is in combining it with

concrete, brickwork, and other materials; but it appears to us such a combination would be still be more advantageous if the iron were completely imbedded or encased in such materials. Thus the "Dennett Arch" offers an example of a compact mass of concrete and iron, the girders being surrounded by the concrete spandrels of arching; there are also other systems of fire-proof construction (*e. g.* Hornblower's) in which the rolled iron joists are completely imbedded and ceiled underneath, and which seem to insure the desired requisites, and which do not expose any considerable surface of metal underneath.

It becomes a serious question, then, how far may iron be used in the construction of floors and roofs without its endangering the actually stability of a building? Or to what extent can iron be used in conjunction with other meterials?

Now, these questions turn upon the possibility of rendering iron less liable to the direct action of fire or heat. Metals are, we all know, the best conductors of heat. Physicists tell us the reason, viz., because their internal structure is homogeneous and uniform; the particles are in close contact; and the vibratory or molecular movement which sets the heat waves in motion is, therefore, regular. All substances which cannot transmit molecular motion readily are bad conductors. Now, it is evident that, if we can combine these two opposite qualities in such a way as will neutralize or destroy the direct action of heat, and, at the same time, without unduly increasing the bulk of our floors and metallic framework, the great problem of how best to utilize iron in construction will be solved. It appears that there are some substances particularly bad conductors of heat; such are brick-earth, composed of a variety of bodies and porous; porcelain, asbestos, pumice-stone, charcoal, sand, &c. These substances are, in fact, such bad conductors that a red hot iron ball may be held some time in the hand if it be first coated with one of them. Such materials offer themselves as coverings for iron girders, columns, &c., and we do not see why compound materials of a porous kind, as animal charcoal and plaster, should not be applied to such ironwork *in situ* by first filleting the girder or column, or surrounding it with a perforated plating of thin earthenware or metal on which to lay the coating, which could be run as moulded work or finished ornamentally. A lining or casing of such materials moulded to the form of the iron to be protected could also easily be prepared in cast blocks, rebated or grooved together, the external facing being moulded to any section. We do not know of any such preparation, but we throw out the suggestion to manufacturers.

Animal charcoal should be one of the ingredients in the compound used, as it is one of the worst known conductors. Fireclay lumps could be well treated in this manner, or plastering—which materials have been suggested lately. Some success has attended the experimental testing of girders and columns cased in plaster and cement, the particulars of which appeared in the "Building News" some time since. A week or two since, the fireproof construction adopted at the National Safe Deposit Company's premises underwent a severe trial at the works of Messrs. Easton & Anderson, Erith, an experimental beam, cased in fireclay lumps, and coated with plastering, being subjected to the action of a continuous flame for one and a half hours, and to a smoldering heat for twenty-four hours. The floor thus subjected formed the top of the furnace, and was composed of two brick arches supported upon an iron girder cased as above, and was loaded to an equivalent distributed load of 3 cwt. to the super. foot. A deflection of 3-16 inch in centre took place. In about an hour after exposure to the fire, the plaster coating cracked, and came off in pieces; and the deflection increased for some hours after the fire was reduced till it reached 1 inch and 3-16 th, after which it diminished, and when the fire was extinguished by a stream of water and the load removed a deflection of 3-8 inch remained. The deflection, however, gradually diminished, and the girder eventually regained its straightness. The fireclay reached a red-heat, but was found afterwards precisely as when put on, "quite uninjured," though some part of the brick side of furnace was forced by the heat out of the perpendicular, possibly by the thrust of the arches.

This experiment has successfully proved that iron protected with fireclay can withstand a fierce heat and yet remain uninjured in its elasticity, while the brick arching and concrete backing can resist any amount of heat likely to occur. We think if an air-space were left between such casing and the iron, it would provide a still

more effectual barrier, though a few perforations would be required in the casing to allow the heated and expanded air to escape. If, also, brick-earth mixed with charcoal were used, a still more effectual non-conducting casing would be obtained, and the iron would be comparatively preserved at a moderate temperature. By thus encasing a good conductor of heat in a bad one, the evils of expansion and contraction are avoided, or considerably lessened, and we are thus left the advantage of using in our construction a material which may aptly be called a "good servant but a bad master."

Not only would non-conductive coverings act as protectors from heat, but they would obviate the inconveniences arising from condensation. Space prevents our consideration of this and other effects of heat, which we may leave to another article; in in the mean time, however, we hope to find the promoters of the Amended Metroplitan Buildings Bill will consider the importance of casing iron likely to be exposed to fire, and the desirability of preserving powers to enforce the employment of fire-resisting and non-conducting materials; to regulate thickness of walls in warehouses, their horizontal and vertical division, and also to insist upon means of compensating for the expansion of iron under heat, and generally to exercise control in the arrangement of inflammable buildings.

PRACTICAL IRONWORK.

From "Engineering."

In offering the following remarks on practical ironwork to the consideration of a meeting of members of one or more grades of this great Institution, of which the author is proud to be a student, no time will be wasted by prefatory detail; but as all present are more or less familiar with the subject, it will simply be assumed that the skeleton of an iron structure has been decided upon, and the strains ascertained to which each of its members are to be subjected, and the purpose of this paper will be to investigate the practical considerations affecting its design, strength and construction.

No attempt will therefore be made to delineate the process by which these strains have been arrived at, as that portion of the subject can only be mastered by deep and patient study of existing structures and standard works on the subject.

In apportioning the proper amount of metal to meet the strain, the first care should be to employ as nearly as possible only iron of the economical sections, weights and lengths to be obtained in the iron market; points not unfrequently overlooked. For instance, L-irons 4 in. by 4 in. by $\frac{1}{4}$ in. can be obtained in lengths of 30 ft. without extra cost, and they are sometimes rolled at an additional cost to 40 ft. in length. At the Vienna Exhibition a Z-section of rolled iron was exhibited 85 ft. in length. L's and T's, and similar sections can be obtained in moderate lengths without extra charge, when the sum of the sides does not exceed 8 in. or 9 in.; with larger sections, such as H-iron, having a depth of about 12 in., the cost will be something over 20 per cent. more than for T or L irons, complying with the above conditions. In the same way an extra price is generally paid for bars exceeding 6 in., although up to 8 in. or 9 in. it is not excessive, and they can be obtained from some manufacturers up to 12 in. in width.

It is in dealing with plates that the term "extra" must always be kept in view, as by bad designing the cost of the iron may be nearly doubled. A plate to cost the ordinary market price must be under 4 cwt. in weight, 15 ft. in length, 4 ft. in width, and must not be of irregular shape. In order to better illustrate this point, a plate 15 ft. by 5 ft., 1 in. by $\frac{3}{8}$ in. may be taken as an example, and the extra charges, according to formal tender made in 1873, by a first-class firm for "Best crown boiler plates," will be:

	£	s.	
For weight	12	0	per ton.
" length	0	0	"
" width	3	10	"
" cutting	0	0	"
In all	15	10	

The price for iron by this tender complying with the previously mentioned conditions was £19. 10*s.*, to which this extra charge must be added, bringing it up to £35

per ton, or nearly double the cost of ordinary plates.

These considerations must be attended to in designing buckled, corrugated or other manufactured forms of plates, as, if they require to be made from iron on which "extras" are charged, their cost will necessarily be enhanced.

At the Vienna Exhibition plates were exhibited 52 ft. 6 in. by 5 ft. 3 in. by 63 in. and 48 ft. 7 in. by 4 ft. 2 in. by 1.23 in., weighing 3 and 4½ tons respectively; these were of course exceptional and very costly plates.

The "extras" for plates do not become very considerable until a weight of 7 cwt. is exceeded, and a width of 4 ft. 6 in.; but when the width of 5 ft. is reached, the extra is charged per inch, and by the tender before referred to it amounts to 10*s.* per inch per ton, in addition to £3 charged extra for a width of 5 ft.

A long plate becomes expensive on account of the difficulty in handling it, and the great care required to be exercised in putting it through the rolls, in order to avoid making it of irregular shape, in which case there is a large amount of waste in cutting the plate to the required length and area, and sometimes it becomes what is technically termed a "waster," which has to be thrown aside; to cover these contingencies, much larger "blooms" have to be made.

Contractors have sometimes to tender for ironwork when the designs contain many of these irregular lengths and dimensions; it then becomes necessary for them to estimate the probability of the conditions of the design being enforced, not always an easy matter; but when the reason for the employment of extra iron is obvious, they tender accordingly. Occasionally designs exhibiting a total ignorance of ironwork come into the contractor's hands, in which case estimating becomes very difficult, and to be on the safe side, a large percentage must be put on to cover contingencies.

The contractor can generally estimate the quality of the work which will suffice by the workmanlike style or otherwise in which the drawings and specifications are made out.

Angle-iron bends and joggles should be as few and simple as possible, and bent or cut plates should be few and far between.

T-stiffeners to the web of a plate-girder, if splayed out clear of the angle-iron, will cost about half as much for smithing as when required to fit close round them, and will answer their purpose equally well; where the flanges are too narrow to admit of four rows of rivets being put through at one cross-section, this form of stiffener cannot be used; where the flange requires only two rows of rivets, but is of sufficient width to admit of two additional rivets, the stiffeners can be generally so arranged that these rivets shall in no way affect the strength of the girder, as owing to the unvarying thickness of plates there is always an excess of strength in the flanges of a plate-girder at points not very far distant, and it is here that the stiffeners should be placed.

The harassing little, but still most important rivets, should be carefully considered, as it is on them that the whole strength of the structure depends—no amount of extra metal in the body of a tie can compensate for a badly constructed joint. The author would advise careful consideration of the position, diameter, and pitch of every rivet previous to placing the design before contractors, as carelessness or ignorance on this point at once indicates the amateur designer, who is often led astray by the facility with which he can ornament his drawings with these little circles or red crosses.

Drawings of ironwork should be as complete as it is possible to make them, free from all ambiguity, leaving no room for doubt as to what is intended; in order to effect which dotted lines must largely be employed. It is impossible to confuse a drawing by putting dotted lines in their proper places, as it must be borne in mind that the drawings are not to be submitted to a parliamentary committee, but to men accustomed to most complicated mechanical drawings. A working drawing is not necessarily pretty; it should be neatly and accurately made, and should require no explanation whatever.

The pitch and diameter of the rivets should in all cases be marked upon the drawings, and their relative positions in the structure should be pointed out. In the construction of a bridge, it is generally necessary to draw the whole or parts of it full sized, with its required curve or camber, in order to ascertain the accurate length of its separate portions and the exact relative positions of the rivets, which will, by this means, be very accurately ascertained; these positions will then be marked on a

template, from which any number of similar plates can be made.

It is usual to specifiy that when one portion of a structure is to be riveted to another, the holes must be made with such accuracy that a template with studs fixed in the relative position of the rivets one-sixteenth less than them in diameter, shall enter all the holes at the same time and go completely through the various thicknesses of plates; if the holes are not fair to one another, the shearing area of the rivet is reduced, and therefore the joint will not be of its calculated strength, to cover which fault it is advisable in calculating the number of rivets to consider their diameter one-sixteenth less than that shown on the drawings; all rivets should have a good and sufficient head, and when inspecting the construction of ironwork this point should be enforced.

The strength of rivet iron will be considered hereafter, but a good practical test is that a rivet shall be hammered, when hot, to less than $\frac{1}{8}$ inch in thickness without showing any sign of cracking.

Although a difference of opinion exists among engineers on the question of drilled *versus* punched holes, it would appear from the following experiments carried out by Mr. Cochrane and kept on record in the Minutes, vol. xxx., that practically there is little to be gained, so far as the strength of the plates is concerned, by using one method more than the other.

A bar of Lowmoor 2 inch $\times \frac{1}{2}$ inch with a drilled hole $\frac{7}{8}$ inch in diameter put through it, sustained 235 cwt., and with a punched hole 226 cwt.; with bars of hard crystalline iron of the same dimensions, that with the drilled hole sustained 250 cwt. and the punched hole 244 cwt. With bars each with three holes, one drilled, one punched, and one punched $\frac{3}{4}$ inch and drilled to $\frac{7}{8}$ inch in diameter, in all cases they broke through the punched hole, which would be inferred from the above results, but which are still well within the limits of variation of the breaking weights of our best irons.

When we leave strength out of the question and consider only workmanship, the method to be adopted must be left to the judgment of the engineer. If a number of plates are to be riveted together or an intricate junction made, unless great care is exercised by a very experienced hand at a punching machine, the drilled holes will be more accurate, but where a simple plate and L-iron are to be joined together the balance of strength in favor of drilling is not sufficient, in the author's opinion, to sanction the extra cost.

A want of proper welding in the lamina of iron may be sometimes detected when punching; it is difficult to punch near the edge of bad iron, but a drill may be put through almost any rubbish.

The cost of cast iron may be greatly enhanced by bad designing, but as civil engineers have not often to deal with very intricate forms it may be sufficient to say that the molten metal is run into moulds, and that, with the exception of very large castings which are built up bodily, these moulds are formed by placing in the sand a pattern in wood of the object to be cast. Of course this is well known to all, but still not always remembered, if we may judge from the number of boxes and cores sometimes required for what ought to be simple castings.

In a casting such as a transverse truss of an arch bridge, the different portions of the truss should have nearly the same amount of cross section, as if this is not attended to the members with the smaller body of metal will cool first, and the remaining portions in cooling will put an initial strain on the iron which may distort or even cause its destruction; for these reasons every precaution should be taken to insure that the casting may cool evenly.

As regards the quality of cast iron, for want of space a few words must suffice. For structural purposes it should be melted at least twice, and mixtures should be made which will stand the following test: A bar 3 feet, 6 inches by 2 inches by 1 inch, run each day from the cupola from which the castings are being made, should, when placed edgeways on 3 feet bearings, sustain a load applied at the centre of 28 to 30 cwt., and give before breaking a deflection of five-sixteenths.

The cast iron of the sleepers for the Great Indian Peninsula Railway had to undergo tests very similar to this, and, in addition, the sleepers had to stand a weight of $3\frac{3}{4}$ cwt. falling a height of 5 feet 6 inches, the same having previously been subjected to blows from this weight falling 2 feet, 2 feet 6 inches, 3 feet, etc., up to 5 feet, 6 inches, being at the time of testing on sand not more than 24 inches deep; the average height required to break the sleepers was

7 feet, 9 inches. The cast iron was also to stand a tensile strain of 11½ tons per square inch, and the average was 13.07 tons, a very high but obtainable result.

It is not advisable to restrict the manufacturer by stating the proportions and classes of iron to be mixed, as he will in most cases be better able to judge of the mixtures to be made in order to produce a specified result. Not that the author would advocate leaving too much to the practical man, as we not unfrequently come across the "miscalled practical man," who will tell you that he is able to judge of iron by its appearance, a statement which must be accepted with caution, as men who have given much more time than most engineers can devote to the study of iron, very often err in their conclusions formed only by inspection. An instance came under the author's notice where a fracture of rod iron was shown and pronounced first-class, and on the other end of this rod, not 6 inches in length, being exhibited it was pronounced little better than trash; in the first instance, the fracture was of a fine silky, fibrous nature, which denotes that the iron is soft, tenacious, and generally of good quality, while in the latter case it presented a rather coarse crystalline fracture, which, owing to the largeness of the crystals, showed that the iron was not quite of a uniform quality, but the appearance was chiefly owing to the mode of testing, as if iron is broken by a sudden strain it invariably presents the crystalline fracture; whereas if good iron, and broken by a gradually increasing strain, the fibrous fracture always results; nevertheless, it is the generally accepted opinion that the fibrous fracture cannot be obtained by any mode of testing from really bad iron; the gradually increasing strain should therefore be applied, and the fibrous fracture must result from good iron, more especially from rolled iron or plates.

Whether the iron is fibrous or crystalline, its quality may to some extent be judged by the fineness of its texture, and the irregularity of its fracture.

Ironmasters are to some extent averse to testing; the author was advised by one of these gentlemen of high standing to exhibit his knowledge of the subject by simply specifying "best merchantable iron," and if, after inspection, it was found not to be good, it could then be tested, but after what has been said it is needless to further point out the impropriety of such a proceeding; it was also hinted that tests were instituted to exhibit the cleverness of engineers, instead of which they simply exposed ignorance, and no doubt there is often room for such remarks.

According to Mr. Edwin Clarke, the permanent set of a bar 10 feet long and 1 square inch in section was for 3 tons, strain $\frac{1}{498.750}$ and at 10 tons $\frac{1}{74.953}$ of its length. The stretch of iron up to 12 tons is to some extent uniform, and may be taken at $\frac{1}{10.000}$ of its length for each ton, but beyond this strain it becomes irregular, which accounts for the ultimate deflection of a beam being almost beyond calculation.

In the early days of engineering it was a common practice to make things strong enough, on the erroneous supposition that a structure tested with something more than its working load would be quite safe. This may or may not be true according to whether the limit of elasticity of the iron is exceeded. If such be the case the ultimate destruction of the structure is only a question of time; under any circumstances the design of a structure on such an hypothesis is now quite inadmissible owing to the increased cost of labor and materials, and the criticism to which a design is always subjected.

The limit of elasticity of iron is that point at which the same strain will produce an increasing permanent set. An example will perhaps more clearly express this important point. If a bar be tested with a load of 8 tons and the permanent set not increased by any number of repeated applications of this load, 8 tons is said to be within the limit of elasticity of the iron; if on the other hand the permanent set increases ever so little, the limit of elasticity has been exceeded.

It would, therefore, be well to specify that iron shall not take an increasing set with 8 or 9 tons, but that with 11 or 12 tons it must show a decided permanent set over and above that obtained with the 8 tons. The latter condition is required in order to insure the first being complied with, as an unprincipled manufacturer might put a higher strain than 8 or 9 tons, and so take all the stretch out of the iron previous to its official testing, in which case any iron would comply with this condition. This point is, in the author's opin-

ion, one of great importance, for supposing the working strain put upon the iron to be 5 tons to the inch, although this may in some cases be only $\frac{1}{5}$th of the ultimate breaking strain, the factor of safety will only be 1.6 in place of 5 as might appear at first sight, that is assuming the limit of elasticity to be 8 tons.

The working strain to which iron is to be subjected is governed by the specified quality and tests to which it is to comply with. In moderately small structures, where the working load is comparatively great in comparison with the weight of the structure, it will be found in most cases more economical to employ an ordinary quality of iron with a small working strain, than to use an exceptionally good material; the working strain of the iron is also governed by the character of the load. In the case of a girder supporting the wall of a building a strain of 5½ tons might with safety be put upon good ordinary iron, but in a small railway bridge of about 20 feet span, where the moving load is to a great extent indeterminable, it is not well to impose a greater strain that 4 or 4½ tons.

From the author's experience and a careful study of the many results obtained by such high authorities as Mr. Kirkaldy, he concludes that ordinary iron to be found in the market should comply with the following conditions:

Rod, bar, and rivet iron should sustain an ultimate tensile strain of 24 tons per square inch, elongate 15 per cent. before breaking, and be reduced in sectional area about 25 per cent. Angle iron, an ultimate tensile strain of 22 tons, elongate 9 per cent., and be reduced in sectional area about 15 per cent. Plates with the fibre an ultimate tensile strain of 20 tons, elongate 6 per cent. and be reduced in sectional area about 8 per cent., and across the fibre 18 tons, elongate 3 per cent., and be reduced in sectional area about 5 per cent.

—	Tons per square inch.	Elongation per cent.	Contraction of area per cent.
Rod, bar and rivet iron	24	15	25
Angle iron	22	9	15
Plates with fibre .	20	6	8
Plates across fibre ..	18	3	5

These requirements are not at all excessive, and should therefore not enhance the price of ordinary Staffordshire beyond the insignificant sums for testing purposes. The samples on which these investigations are to be carried out ought to be from 8 inches to 10 inches in length, between the points of attachment. The toughness and ductility of the iron can be estimated, either from the contraction of area or elongation; it is unnecessary, therefore, to investigate both of these points, the choice between them being decided by the facility with which they can be ascertained, but where the experiments are to be carried out at testing works, such as those of Mr. Kirkaldy, it is immaterial which is specified, as by experience either may be ascertained with equal precision.

No doubt the carrying out of tests will involve the expense of continuous inspection, but the engineer by vigorously enforcing his specification, will not only gain the esteem of every honest contractor, but will have the satisfaction of knowing that he is obtaining good materials and workmanship.

On the completion of the structure it should be tested with a load slightly greater than its working load, and the deflection noted. This test of workmanship must only be taken in conjunction with the test of materials, as a joint or portion of the structure might be on the point of breaking and yet not stretch sufficiently to materially alter the deflection, and hard brittle iron under the deflection test may appear superior to a better and more desirable quality.

If an iron structure is well designed, erected, and taken care of, the author can see no reason why the term "life of ironwork" should not become a thing of the past, as iron imbedded in concrete has been found at the expiration of twenty years as free from decay as on the day of its manufacture.

A few words on the preservation of ironwork will, therefore, perhaps not be out of place. It is advisable to coat a casting with oil, paint, or tar, as soon as it leaves the sand, as by so doing the hard outer skin is preserved, and when in position it should be again coated. When cast iron is to be covered up, a preparation of coal tar and naphtha is found to answer well; this may also be used to advantage for the upper surface of buckled plates or other forms of road platforms.

Wrought iron when hot from the rolls is sometimes brushed over or dipped into boiled linseed oil, but a better and less expensive way, in the author's opinion, would be to brush it over with boiling hot oil when cut to something like its permanent shape, and after its workshop manipulation to again treat it with oil; previous to being erected any abutting surfaces should be also coated with red lead or other metallic paint. A preferable way, if thoroughly carried out, would be to let the iron slightly rust and have it well scraped before its treatment with oil, as by so doing the oxide or blue shales, which in a more or less degree are inseparable from its manufacture, would be removed; they are very apt to peel off after a short time and bring the paint with them, more especially in a structure subject to vibration. This is not of such vital importance for home work under constant supervision, but for foreign up-country-work too much care cannot be taken to preserve the surface of the iron from atmospheric and other influences.

All work should be so designed to allow of its being painted, and plates less than ¼ inch in thickness should never be used. The linseed oil brushed over the iron, as before pointed out, will form a kind of varnish, and is an excellent preparation for the after coats of red lead or other metallic paint, of which not less than two coats should be used, the last being of approved color and put on after the work is erected in place. On account of the great cost of red lead, other metallic paints are now generally substituted, as that expensive ingredient was often replaced by colored earths, which were mixed with bad oils, and it is needless to state that the quality of the paint is, to a great extent, governed by the oils with which it is made.

All tooled surfaces should be well covered with tallow and white lead. Those wishing to become acquainted with the practical items of ironwork cannot do better than study "Works in Iron," by Mathieson, and experiments on wrought iron and steel, by Kirkaldy; but a year devoted to the vice and bench in a good ironwork or general mechanical shop will be of more service than any amount of reading, and we have it on no less authority than Mr. John Fowler, that a mechanical training is absolutely essential to those aspiring to any eminence as civil engineers.

In conclusion the author trusts his *confrères* exonerate him from any desire or attempt to exceed his province as a student, by the terms which he has found it necessary to employ in his treatment of "practical ironwork."

ELASTICITY OF BUILDING MATERIALS.

From "The Building News."

When two balls of ivory, hard wood, or metal impinge against each other with a force very much less than that which would suffice to break them, a rebound takes place one from the other, which is caused by a slight flattening having been produced at the point of contact; and the force of this recoil depends upon the power possessed by the material of resuming its former shape: this power is the measure of the "elasticity" of the body, or its tendency to resist any displacement of its fibres. No material is perfectly elastic; the fibres or particles of the body strained never exactly recovering their original position; hence a large succession of blows will gradually alter the shape of the body, provided they are not sufficiently strong to produce fracture. There are, however, many degrees of elasticity in various materials, which can be discovered by carefully conducted experiments; thus, if two balls of the material to be tested are suspended by threads, so as to move in an arc of a circle, and allowed to fall towards each other from a certain height, they will not return to the point from which they started, but to some point short of it, the arc traversed in the recoil, as compared with that traversed in the descent, giving the measure of the "elasticity" of the material, or the ratio of the force of restitution to that of compression. In this way the relative elasticity of several bodies has been ascertained; taking 100 to represent perfect elasticity, or the distance on the arc or scale from which the bodies start towards each other, it is found that glass has the greatest power of restitution, its elasticity being as high as 94; that of hard

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baked clay is 89; of ivory, 81; of limestone, 79; of hardened steel, 79; of cast iron, 73; of soft steel and bell-metal 67; of elm wood, 60; of brass, 41; and of lead, 20. This mode, however, of testing the elasticity of bodies tells us very little about the actual elastic force residing in the material; for although glass has a much higher elasticity than steel, yet a blow that would not make the slightest impression on the latter would smash the former to atoms. For practical purposes we have, therefore, to ascertain by a different class of experiments what force a body will withstand without injury to its elasticity or power of retaining the shape that has been given to it.

When a straight bar or rod of any hard material is fixed at one end, and a pressure applied to the other, a bending in the direction of the pressure will be produced, the amount of which depends on the relative proportions of the bar, and the amount of force applied. In some materials, such as brick or stone, the bending will hardly be perceptible, as the application of a weight that would produce any appreciable amount of flexure would fracture the material; with iron, steel, wood, and many other substances, the case is very different, the amount of bending being very considerable before injury or fracture takes place; when, however, the pressure is removed the bar never returns exactly to its original straightness, but retains a "set" or alteration of form, owing to the imperfection of its elasticity. Thus in an experiment that was tried on a small cast-iron bar whose section was the form of ⊥, which was supported at each end and loaded in the middle, and of which the breaking weight was found to be 1,120 lbs., the deflection in the centre, or deviation from a straight line, caused by a load of 14 lbs., was 1-40th of an inch, and the set after the removal of the load was just perceptible; with a load of 56 lbs. the deflection was 4-30th of an inch, and the set 1-200th of an inch; but with 112 lbs. the set was three times as great as with 56 lbs. Hence it appears that however small the strain the elasticity is to some extent weakened thereby, and, consequently, the resisting power of the material. Fortunately, however, the set does not go on increasing in any perceptible degree as long as the beam is loaded with a weight very much less than that which would cause fracture, this ratio varying in different materials from 1-3rd to 1-10th of the breaking load.

Another mode of testing the elasticity of a material is to subject it to a stretching force in the direction of its length; if the material was perfectly elastic it would, after being elongated by the force applied, return to its original length as soon as the strain was taken off; that it never does so is evident from the following experiments:—A rod of cast iron 50 feet long and 1 inch square being subjected to a stretching force was found to require 16,000 lbs. to tear it asunder; but before this was done it was gradually strained by a succession of weights, and when the strain amounted to 1-10th of the breaking weight it stretched 11-150ths of an inch, and the permanent set when the load was removed was 1-500th of an inch; with double this load the rod stretched just twice as much, but the set was 1-100th of an inch, or five times as much as before; with half the breaking weight the extension was nearly ½ an inch, and the set 1-20th of an inch, the ultimate extension at the moment of fracture being 1 inch. Hence we see that cast iron, when subjected to tensile strain, possesses a high degree of elasticity as long as the stretching force applied is only a small proportion of the breaking force, since the "set" is but 1-30th of the actual extension produced by 1-8th of the breaking weight, and amounts to 1-15th of the extension when the strain is ¼ of the breaking weight. We may therefore consider that for all practical purposes cast iron is perfectly elastic under a tensile strain as long as it does not exceed 1-8th of that which would tear it assunder; also that within this limit the elongation is proportional to the strain; hence if L is the original length, l the extension produced by a force S, E a constant number called the "modulus of elasticity," then

$$l : L :: S : E$$

If we make l equal to L, then S will be equal to E; and hence it appears that E is the force necessary to elongate a rod one square inch of section by a quantity equal to its original length. The value of E has been determined for many solid bodies by experiment, and is employed in all calculations of the resistance of bodies to change of form. If S is the force that will produce an elongation l in a rod 1 inch square, then $S \times A$ is the force which will produce the same extension, in one of A inches in sec-

tion; or putting $S \times A = F$, we have

$$S = \frac{F}{A};$$

and since $E : S :: L : l$.

Therefore

$$E : \frac{F}{A} :: L : l, \text{ and } l = \frac{F.L}{E.A},$$

or,
$$F = \frac{E.A\ l}{L}.$$

The value of l gives us the elongation produced by a given force F, and the value of F in the last equation gives the force required to produce a given elongation l. Putting

$$S = E\frac{l}{L},$$

we have $F = S \times A$. The "modulus of elasticity E is the constant relation existing between the tension per unit of area, and the corresponding proportional elongation which it produces. From the foregoing experiment we can, therefore, deduce the numerical value of E, since

$$E = S\frac{L}{l};$$

and when $S = 4{,}480$ lbs.,

$$\frac{L}{l} = \frac{50 \times 12}{\frac{1}{2}}, \quad \therefore E = 13{,}440{,}000 \text{ lbs.},$$

for cast iron.

When a bar is subjected to a compressive force in the direction of its length, it is shortened thereby in proportion to the force applied; but when the pressure is removed its elasticity enables it to return to its original length, or very nearly so, provided the amount of pressure has not approached near to that which would crush the material. An experiment of this kind was made on a bar of cast iron, 10 feet long and 1 inch square, inclosed in an iron frame to prevent bending, the compressing force being applied at one end. Under a pressure of 4,200 lbs. the bar yielded 1-23rd of an inch, and when the load was removed the "set" was scarcely perceptible, being only 1-14th of this decrement. Under 6,300 lbs. the compression was 1-15th of an inch, the set bearing the same proportion thereto as before. With a load of 8,400 lbs. the bar yielded 1-12th of an inch, but the set was 1-10th of the compression; also with 10,500 lbs. the set was in like proportion to the compression, which was a little over 1-10th inch. With an increase of the force the set increased more rapidly in proportion to the compression, being more than 1-8th of it when the load was 21,000 lbs. Taking the compression under a force of 8,400, we find the modulus of elasticity from the equation

$$E = S\frac{L}{l},$$

namely, $E = 11{,}454{,}545$ lbs. for cast iron under compression.

When bars of wrought iron are subjected to tensile strains, they will stretch much more than those of cast iron before breaking, and the set is very small until the strain reaches one-half that which will tear the fibres asunder. A bar 1 inch square, and 10 feet long stretched 1-22nd of an inch under a strain of 10,670 lbs., which was 1-5th of the breaking load, and on its removal it recovered its original length almost exactly, the "set" hardly amounting to 1-100th of the extension produced; with double the strain the extension was twice as great, but the set nearly four times as much as before; with half the breaking load the extension was nearly 1-8th of an inch, and the set 1-100th inch, or 24 times as great as with a strain of 1-5th the breaking load. In this case the elasticity was but slightly impaired under a strain equal to half that which would destroy the material, since the extension was in proportion to the force applied. Hence we find the value of E for this material to be 27,834,783 lbs. for tensile strain, by taking the value of l, when $S = 10{,}670$ lbs.

The elasticity of wrought iron under a compressive force has been determined by experiments similar to those employed for cast iron, by inclosing a rod 10 feet long and 1 inch square, in an iron frame, to prevent it from bending. Under a pressure of 10,000 lbs., the decrement of length was 1-20 inch; with 20,000 lbs., it was 2-20 inch; and with 30,000 lbs. it was 3-20 inch; showing that the law of compression being proportional to the load held good to that extent, and that the elasticity of the material was hitherto unimpaired; in this case the "set" increased nearly as the square of the compression of each renewal and removal of the load. Beyond 30,000 lbs. on the square inch, the compression increased with greater rapidity the elasticity being evidently impaired thereby, so that we may consider this as the utmost compressive strain to which wrought iron can be safely subjected. Taking the compression under a weight of 20,000 lbs., we find,

in the same way as before, E=24,000,000 lbs. for wrought iron under compression.

The value of the modulus of elasticity (E) is required when we want to calculate the deflection which a beam will undergo when supported at the ends and loaded in the middle; in which case the amount of deviation from a straight line is found by multiplying the weight into the cube of the length, and dividing by the moment of inertia of the section of the beam taken about its neutral axis, and by 48 times the modulus of elasticity. Hence the value of E can be calculated by observing the deflection produced by a given load. Thus, the moment of inertia of a rolled iron joist of I section is $12\ (b.\ D^3 - b - t.\ d^3)$, where b is the breadth of the flanges, D the total depth, d and t the depth and thickness of the web; the deflexion of this beam was .016 inch for every 2,240 lbs. laid on the centre, the span being 54 inches; therefore

$$E = \frac{W \times l^3}{48 \times .016} \times \frac{1}{12\ (b.D^3 - b - t.d^3)} =$$

22,467,200 lbs., the depth D being 5 in., d $2\frac{1}{2}$ in., b $2\frac{1}{8}$ in., and t $\frac{7}{8}$ in.

By means of the modulus of elasticity we can therefore find how much deflection to expect when a beam is subjected to a given load, and can regulate the dimension thereof so that its deflection shall not exceed a fixed amount. When the load is uniformly distributed over the entire length of the beam, the deflection at the centre is $\frac{5}{8}$ths of that produced by the same load all applied at the centre.

The elasticity of steel is much more perfect than that of iron, and consequently it can be loaded with a greater proportion of its breaking weight without injury. A bar of hardened steel 1 inch square being laid on two supports 54 inches apart, a load was applied at the centre beginning with 50 lbs., and increasing gradually by that amount until it reached 1,400 lbs. Under 800 lbs. the deflection was 1 inch; with 1,000 lbs. it was $1\frac{1}{4}$ inch, and with 1,200 lbs. a little over $1\frac{1}{2}$ inch, showing the increase of deflection to be nearly as the strain. With a load of 1,200 lbs. a slight "set" was observed, amounting to .016 inch, which was quadrupled by the addition of another 50 lbs.; from this point the deflection and set increased more rapidly, being 1 4-5ths of an inch and .133 inches respectively, under a strain of 1,300 lbs., and with 1,350 the set was .429 inches; hence it appears that the elasticity remained perfect until the load exceeded 1,200 lbs.

A bar of steel being subjected to a tensile strain, showed no indication of a set until the strain was one-half that which would tear it asunder, so that this material may be strained to that extent without injury to its elasticity. The same may be said of steel when it is subjected to a crushing or compressive force. The modulus of elasticity of the best steel is 31,000,000 lbs., but very much less for the inferior qualities.

Wood is a material whose elasticity is easily impaired, for if once it is bent it retains the curvature given to it, so that the strain to which it is subjected must fall very far short of that which would cause fracture. The moment of inertia of a rectangle about an axis through its centre being

$$\frac{1}{12} b d^3,$$

where b is the breadth and d the depth, the value of E is obtained from the deflection (δ) of a rectangular beam loaded in the middle and supported at each end, from the equation

$$E = \frac{W}{4\delta} \times \frac{l^3}{b\ d^3}.$$

The deflection of an oak beam 2 in. square and 84 in. long, was 1.28 in. with a load of 200 lbs., hence

$$E = \frac{200}{4 \times 1.28} \times \frac{84^3}{2 \times 2^3} = 1{,}447{,}031 \text{ lbs.}$$

From this formula we can find the breadth to be given to a beam of known depth and span in order that the deflection under a certain weight shall not exceed a fixed amount; for

$$b = \frac{W.\ l^3}{4\,E.\ \delta.\ d^3}.$$

The modulus of elasticity for fir can be found by a similar experiment; the deflection of a fir batten 3 in. deep and $1\frac{1}{2}$ in. thick, with a span of 72 in., amounted to $\frac{1}{4}$ in. under a load of 120 lbs.; hence

$$E = \frac{W}{4\delta} \times \frac{l^3}{b\ d^3} = 1{,}105{,}900 \text{ lbs. for fir.}$$

Another similar batten gave a deflection of $\frac{1}{8}$ inch under the same load with a span of 8 feet; consequently we have E=1,310,720 lbs. in this case; and another with 10 feet span deflected 1 inch with the same

load, giving E=1,232,213 lbs., which is about the average of the three numbers.

The importance of a knowledge of the elasticity of materials can scarcely be overestimated, since the bending or "sagging" of a beam supporting the wall of a house or other heavy permanent load will cause settlements in all parts of the building, even if it does not actually endanger the stability of the structure.

THE ECONOMIC DEPTH OF TRUSSES.

By S. H SHREVE, C. E.

Written for Van Nostrand's Magazine.

Among the many interesting problems which present themselves during the investigation of the subject of strains in trusses, that of the economical distribution of material has received but little attention; certain proportions have been taken and certain precedents followed without much thought being given to the matter. It is true, that as yet, owing to some unsettled points, theory will enter to some extent into discussions of economy of material, but our assumptions are very closely allied to facts, and the results which may be obtained have great practical value. In many special cases the proportions for stiffening, for joints, for horizontal bracing, and for other parts which have been assumed at a certain percentage, may be definitely fixed, and enable us to obtain results which are accurate.

Certainly that which tends to solve the problem:—given the span and the weight to be carried to determine the most economic form or depth of truss—must, at least, be interesting to the practical engineer.

It is the latter question, that of the economic depth of truss, that we propose investigating in the present paper.

Disregarding its own weight, the quantity of material in a member of a truss varies directly as its length and the amount of strain to which it is subject. Thus a wrought-iron rod or bar subject to tension must have, for a safe working load, a section of 1 sq. in. for each 11,000 lbs. of strain to which it is subject; or if S represent the load or strain which the rod is supporting, its correct section will be $\frac{S}{11000}$; and since a bar 1 in. square and 1 ft. long weighs 3.368 lbs., $\frac{3.368\,S}{11000}$ is the weight of 1 ft. of the bar or rod, and multiplying by r, the length of the rod, we have

$$\frac{rS}{3266} = Q, \quad \ldots \quad (1),$$

the weight of a rod whose length is r, which will safely support the load or strain S.

The same process of reasoning applies to a strut or column subject to compression, only since 9,000 lbs. may be taken as the safe compressive load for wrought iron, Eq. (1) may be changed to

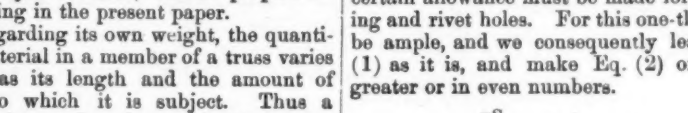
$$\frac{rS}{2672} = Q, \quad \ldots \quad (2).$$

No allowance is here made for the extra quantity of material required for joint connections, and it is not necessary at this point in the case we are considering, to allow any, since our results do not affect the number of joints; but in the struts a certain allowance must be made for stiffening and rivet holes. For this one-third will be ample, and we consequently leave Eq. (1) as it is, and make Eq. (2) one-third greater or in even numbers.

$$\frac{rS}{2004} = Q, \quad \ldots \quad (3)$$

is the weight of a strut subject to a strain S.

Let Fig. (1) represent a truss with a



simple system of bracing consisting of vertical struts and inclined ties, then the Eq.

$$= \frac{(w'+w)x}{2d} - \frac{(w'+w)x^2}{2dl}, \qquad (4),$$

will give the strains in the chord members when the truss is fully loaded.

Here w' = the weight of the uniformly distributed movable load,
w = the weight of the truss,
l = the length of the truss,
d = the depth of the truss,
x = the distances of the ends of the chord members from the abutment and is measured in the upper chord to the ends nearest the centre and in the lower chord to the ends nearest the abutment and is confined to values not exceeding $\frac{l}{2}$.

Let p = the length of the chord members; hence we can obtain the weight of any upper chord member by substituting Eq. (4) for S of Eq. (3) and multiplying by p instead of r; or the weight of any upper chord member is

$$\left(\frac{(w'+w)x}{2d} - \frac{(w'+w)x^2}{2dl}\right)\frac{p}{2004} = Q. \qquad (5)$$

The successive values of x in this equation are p, $2p$, $3p$, etc., to $\frac{np}{2}$, n being the number of panels in the truss; so that by substituting these values in the equation and summing the series thereby formed, we evidently obtain the weight of one-half of the upper chord.

Taking the first term of Eq. (5) we find that it increases in arithmetical progression, thus:

$$\frac{w'+w}{2d}\left(p + 2p + 3p \ldots . \frac{np}{2}\right),$$

and the sum of this series is

$$\left(\frac{w'+w}{2d}\right)p\left(\frac{n^2+2n}{8}\right). \qquad (6)$$

The second term becomes

$$\frac{w'+w}{2dl}\left(p^2 + 4p^2 + 9p^2 \ldots . \frac{n^2p^2}{4}\right)$$
$$= \frac{w'+w}{2dl}p^2\left(1 + 4 + 9 + \ldots . \frac{n^2}{4}\right);$$

and the sum of this series is,

$$\frac{w'+w}{2dl}p^2\left(\frac{n^3+3n^2+2n}{24}\right). \qquad (7)$$

Replacing these terms in Eq. (5) and for np putting its value l, we obtain,

$$\left\{\left(\frac{w'+w}{2d}\right)\frac{ln+2l}{8} - \left(\frac{w'+w}{2dl}\right)\times \left(\frac{l^2n+3l^2+2pl}{24}\right)\right\}\frac{p}{2004}$$
$$= \frac{w'+w}{4008d}\left(\frac{l^2}{12} + \frac{pl}{8} - \frac{p^2}{12}\right),$$

and doubling this,

$$= \frac{w'+w}{2004d}\left(\frac{l^2}{12} + \frac{pl}{8} - \frac{p^2}{12}\right) = Q. \quad . \quad . \quad (8)$$

is the quantity of material in the upper chord. For the lower chord from Eqs. (1) and (4) we have similarly,

$$\left(\frac{(w'+w)x}{2d} - \frac{(w'+w)x^2}{2dl}\right)\frac{p}{3266}, \quad . \quad . \quad . \quad (9)$$

but in this case the limit of the values of x is $\frac{np}{2} - p$, as will be seen by reference to the figure. Performing the same process as with the equation for the upper chord, Eq. (9) becomes

$$\frac{w'+w}{3266d}\left(\frac{l^2}{12} - \frac{pl}{8} - \frac{p^2}{12}\right) = Q. \quad . \quad . \quad (10)$$

the quantity of material in whole lower chord. Adding Eqs. (8) and (10), we have

$$\frac{(w'+w)l^2}{14903.4d} + \frac{(w'+w)pl}{4085.6d} - \frac{(w'+w)p^2}{1490.3d} = Q.$$

or, since the last two terms of the equation will not amount to more than a very small percentage of the whole quantity, they may be omitted and we shall have

$$\frac{(w'+w)l^2}{14903.4d} = Q. \quad . \quad . \quad (11)$$

for the quantity of material in the two chords.

The strain upon any strut from the constant load will be given by the following equation:

$$V = \frac{w}{l}\left(x - \frac{p}{2}\right). \quad . \quad . \quad (12)$$

Here x is measured from the centre of the truss to the strut and the load is considered as concentrated at the lower chord panel points.

Substituting Eq. (12) for S in Eq. (3), and for r the length of a strut, d, we have

$$\frac{\frac{w}{l}\left(x - \frac{p}{2}\right)d}{2004} = \frac{wxd}{2004l} - \frac{wpd}{4008l} = Q. \quad . \quad (13)$$

the quantity of material in any strut distant x from the centre of the truss. The different values of x are, as before, p, $2p$, $3p$, etc., to $\frac{np}{2}$, whence, summing the series and putting l for np we obtain for the first term,

$$\frac{wd}{2004}\left(\frac{n}{8} + \frac{1}{4}\right),$$

and for the second term, which is a constan

and applies to every strut, and consequently to be multiplied by $\frac{n}{2}$, we get,

$$\frac{wdl}{8016},$$

whence,

$$\frac{wdl}{2004}\left(\frac{n}{8}+\frac{1}{4}\right)-\frac{wdl}{8016}=\frac{wdn}{16032}=Q. \quad . \quad (14)$$

the quantity of material in one-half the strut and

$$\frac{wdn}{8016}=Q. \quad . \quad . \quad (15)$$

the quantity of material in all the struts from the constant load.

But $n=\frac{l}{p}$, whence Eq. (15) becomes

$$\frac{wdl}{8016\,p}=Q, \quad . \quad . \quad (16)$$

or the quantity of material in the struts required for the constant load varies directly as the depth and as the length of the truss, and inversely as the length of the panels, while the quantity of material in the chords varies inversely as the depth, and may be considered here to be unaffected by the length of the panels.

The strain in any strut is to the strain in the tie attached to its upper end as the length of a strut is to the length of a tie, or since the length of a tie$=\sqrt{(p^2+d^2)}$

$$d:\sqrt{(p^2+d^2)}::\frac{w}{l}\left(x-\frac{p}{2}\right)$$
$$:\frac{w}{dl}\left(x-\frac{p}{2}\right)\sqrt{(p^2+d^2)} \quad . \quad (17)$$

is the strain in any tie, x being the distance from the centre of the truss to the upper end of the tie.

Substituting Eq. (17) for S in Eq. (1), and for r the length of a tie $\sqrt{(p^2+d^2)}$ and performing the same process we have just done with the struts, we obtain for the quantity of material in the ties,

$$\frac{wn}{13064\,d}(p^2+d^2)=Q \quad . \quad (18)$$

varying with the length of the tie and greater with an increased depth of truss.*

The equation for the strain upon the braces from the moving load is

$$V=\frac{w'\left(x-\frac{p}{l}\right)^2}{2l^2}, \quad . \quad . \quad (19)$$

Where $x-\frac{p}{2}$ is the extent of the load measured from one abutment, and x is the distance from that abutment to the strut whose strain is given by the equation. To apply Eq. (19) we must substitute it for S in Eq. (3) and make $r=d$, the length of a strut. The different values of x are p, $2p$, $3p$, etc., to np. But the greatest strains upon the struts are produced when the truss is half or more than half loaded so that the different values of x are from $\frac{np}{2}$ to np.

Substituting these values in Eq. (19) and summing the series, we have for the amount of strain in the struts of one half the truss, excluding the centre one,

$$\frac{7\,w'n}{48}-\frac{w'p}{48l}=S,$$

or for the whole truss,

$$\frac{7\,w'n}{24}-\frac{w'p}{48\,l}=S. \quad . \quad . \quad . \quad (20)$$

This does not give the strain upon the centre strut, which may be obtained from Eq. (19) by making $x=\frac{l}{2}$, which gives

$$\frac{w'}{8}-\frac{w'p}{4l}+\frac{w'p^2}{8l^2},$$

and adding this to Eq. (20) we have,

$$\frac{7\,w'n}{24}-\frac{7\,w'p}{24\,l}+\frac{w'}{8}+\frac{w'p^2}{8l^2}=S. \quad . \quad . \quad (21)$$

Substituting this in Eq. (3) and for r putting d, we have,

$$\left(\frac{7\,w'n}{24}-\frac{7\,w'p}{24\,l}+\frac{w'}{8}+\frac{w'p^2}{8l^2}\right)\frac{d}{2004}=Q \quad . \quad (22)$$

for the quantity of material required for the struts; and for the ties, as in the previous case of the constant load,

$$\left(\frac{7\,w'n}{24}-\frac{7\,w'p}{24\,l}+\frac{w'}{8}+\frac{w'p^2}{8l^2}\right)\frac{p^2+d^2}{3266\,d}=Q. \quad (23)$$

Collecting the equations we have obtained for the different parts, we have,

$$\frac{(w'+w)l^2}{14963\,4\,d}+\left(\frac{7\,w'l}{24\,p}-\frac{7\,w'p}{24\,l}+\frac{w'}{8}+\frac{w'p}{8l^2}+\frac{wl}{4\,p}\right)$$
$$\left(\frac{d}{2004}+\frac{p^2+d^2}{3266\,d}\right)=Q \quad . \quad . \quad (24)$$

for the total quantity of material in the truss.

If, for convenience, this equation be put in this shape

$$\frac{A}{d}+B\left(\frac{d}{a}+\frac{p^2+d^2}{bd}\right)=Q. \quad . \quad (25)$$

where the values of A, B, a and b are easily

* Stoney, page 182, is of a different opinion. He states, "Hence we conclude that altering the depth of braced girders does not affect the amount of bracing."

seen, and then differentiated with d as a variable, we will obtain for its value, which will make the equation or the quantity of material a minimum,

$$d = \sqrt{\left(\frac{ap^2}{a+b} + \frac{A\,ab}{B\,(a+b)}\right)} \quad . \quad (26)$$

By replacing the quantities of Eq. (24) in this equation and reducing it to its simplest form we obtain for the value of d,

$$d = \sqrt{\left\{ .38\,p^2 + \frac{2\,l^4 p\,(w'+w)}{w'\left\{7\,l^2\,(l-p^2) + 3\,l^2 p + 3\,p^3\right\} + 6\,l^2 w}\right\}} \quad (27)$$

Let w'=200,000 w=100,000, l=200, and p=10, and by substituting these values in the equation we shall obtain for that depth of truss which shall require the smallest quantity of material

$$d = \sqrt{\{38 + 592\}} = 25 \text{ ft.}$$

If we assume the amount of horizontal bracing and the allowance for joints, etc., to be a certain percentage of the weight of the bridge, and we add this, together with the weight of the track to Eq. (24), we shall then obtain the value of w or the weight of the bridge. Thus, let the horizontal bracing and the extra amount of material required for joints and connections be 25 per cent. of the weight of the bridge and the weight of the track, etc.. to be, say 250 lbs. to the foot, then,

$$\frac{(w'+w)\,l^2}{14903.4\,d} + \left(\frac{7\,w'l}{24\,p} - \frac{7\,w'p}{24\,l} + \frac{w'}{8} + \frac{w'p}{8\,l^2} + \frac{wl}{4\,p}\right) \times \left(\frac{d}{2004} + \frac{p^2+d^2}{3266\,d}\right) + .25\,w + 250\,l = w. \quad (28)$$

or,

$$w = \left(\frac{w'l^2}{14903.4\,d} + \left(\frac{7\,w'l}{24\,p} - \frac{7\,w'p}{24\,l} + \frac{w'}{8} + \frac{w'p}{8\,l^2}\right)\left(\frac{d}{2004} + \frac{p^2+d^2}{3266}\right) + 250\,l\right) \div \left(.75 - \frac{l^2}{14903.4\,d} - \frac{l}{4\,p}\left(\frac{d}{2004} + \frac{p^2+d^2}{3266}\right)\right) \quad (29)$$

Let w'=400,000, l=200, d=25, and p=10, and substitute these values in this last equation and we shall obtain for the weight of the bridge, w=268,071 lbs.

RECENT PROGRESS IN MECHANICAL ENGINEERING.*

From "The Telegraphic Journal."

In railroad engineering, one of the most important topics for consideration, as it appears to me, is that which relates to the abatement of dangers in the conducting of the traffic.

Gradually, during a period of twenty or thirty years past, a very fine system of watching, signalling, and otherwise arranging for the safety of trains, has been contrived, and very generally introduced along our principal line of railroad. In saying this, I allude chiefly to the block system of working railways, with the aid of telegraphic signals and interlocking mechanisms for the working of the points and signals.

In former times it was customary to allow a certain number of minutes to elapse after a train passed any station, or junction, or level crossing, or other point where a servant of the company was stationed, before the succeeding train was allowed to pass the same place. Thus at numerous points along the line a time interval was preserved between successive trains. It was quite possible, however, that the foremost of the two trains, after passing any of these places where signals were given, might become disabled, or might otherwise be made to go slowly, and that the following train might overtake it, and come into violent collision with it from behind. In order to provide against the occurrence of such accidents a system was introduced called the *block system;* and its main principle consists in dividing the line into suitable lengths, each of which is called a *block section*, and allowing no engine or train to enter a block section until the previous engine or train has quitted that portion of the line. In this way a space interval of at least the length of a block section is preserved between the two trains at the moment of the later train's passing each place for signalling; and the risk of this space interval becoming dangerously small by negligence or other accidental circumstances, as the later train approaches the next place for signalling, is almost entirely avoided.

Further, at each signalling station, the va-

*Abstract of the address of Prof. James Thompson, LL D, to the Mechanical Section of the British Association.

rious levers or handles for working the points, and those for working the semaphore signals for guiding the engine-drives, instead of being—as was formerly the case—scattered about in various situations adjacent to the signalling stations, and worked often some by one man and some by another, without sufficient mutual understanding and without due harmony of action, are now usually all brought together into one apartment called the signal-cabin. This, cabin, like a watch-tower, is usually elevated considerably above the ground, and is formed with ample windows or glass sides, so as to afford good views of the railway to the man who works the levers for the semaphores and points, and who transmits by electricity signals to the next cabins on both sides of his own, and, when necessary, to other stations along the line of railway.

The interlocking of the mechanisms for working the points and for working the semaphores, which, by the signals they show control the engine-drivers, consists in having the levers by which the pointsman works these points and signals so connected that the man in charge cannot, or scarcely can, put one into a position that would endanger a train without his having previously the necessary danger-signal or signals standing so as to warn the engine-driver against approaching too near to the place of danger.

The latest important step in the development and application of the block system is one which has just now been made in Scotland, on the Caledonian Railway. Before explaining its principle, I have first to mention that a semaphore arm raised to the horizontal position is the established danger-signal, or signal for debarring an engine-driver from going past the place where the signal is given. Now the ordinary practice has been, and still is, to keep the semaphore arm down from that level position, and so to leave the line open for trains to pass, except when the line is blocked by a train or other source of danger, on the block section in front of that semaphore, and only to raise the semaphore arm exceptionally as a signal of danger in front. The new change, or improvement, now made on the Caledonian Railway consists mainly in arranging that along a line of railway the semaphore arms are to be regularly and ordinarily kept up in the horizontal position for prohibiting the passage of any train, and that each is only to be put down when an approaching train is—by an electric signal from the cabin behind—announced to the man in charge of that semaphore as having entered on the block section behind, and when, further, that man has—by an electrical signal sent forward to the next cabin in advance—inquired whether the section in advance of his own cabin is clear, and received in return an electrical signal meaning "*The track is clear; you may put down your debarring signal, and let the train pass your cabin.*" The main effect of this is, that along a line of railway the signals are to be regularly and ordinarily standing up in the debarring position against allowing any train to pass; but that just as each train approaches, and usually before it has come in sight, they go down almost as if by magic, and so open the way in front of the train if the line is ascertained to be duly safe in front; and that immediately on the passage of the train they go up again, and, by remaining up, keep the road closed against any engine or train whose approach has not been duly announced in advance, so as to be known at the first and second cabins in front of it, and kept closed unless the entire block section between these two cabins is known to have been left clear by the last preceding engine or train having quitted it, and is sufficiently presumed not to have met with any obstruction, by shunting of carriages or wagons, or by accident, or in any other way. This new arrangement, which appears to be a very important improvement, has already been brought into action with success on several sections of the Caledonian Railway; and it is being extended as rapidly as possible on the lines of the Caledonian Company, where the ordinary mode of working the block system has hitherto been adopted.

The mechanisms and arrangements I have now briefly mentioned are only a portion of the numerous contrivances in use for abatement of danger in railway traffic. It is to be understood that by no mechanisms whatever can perfect immunity from accidents be expected. The mechanisms are liable to break or to go wrong. They must be worked by men, and the men are liable to make mistakes or failures. We shall continue to have accidents; but if we cannot do away with every danger, there is no reason why we should not abate as many dangers as we can.

Within the past twenty years very remarkable progress has been made in steam

navigation generally, and more especially, I would say in oceanic steam navigation. In this we meet with the realization of great practical results from the combination of improved mechanical appliances and of physical processes depending on a more advanced knowledge of thermo-dynamic science.

The progress in oceanic steam navigation is due mainly to the introduction jointly of the screw propeller, the compound engine, steam-jacketing of the cylinders, superheated steam, and the surface-condenser.

The screw propeller, in its original struggle for existence, when it came into competition with its more fully developed rival, the paddle wheel, meet with favoring circumstances in the want—then strongly felt—of means suitable for giving a small auxiliary steam-power to ships arranged for being chiefly propelled by sails. For the accomplishment of this end the paddle-wheel was ill-suited; and so the screw propeller got a good beginning for use on long oceanic voyages. Afterwards, in the course of years, there followed a long series of new inventions and improved designs in the adaptation of the steam-engine for working advantageously with the new propeller; and it has resulted that now, instead of the screw being used as an auxiliary to the sails, the sails are more commonly provided as auxiliaries to the screw. For long oceanic voyages it became very important or essential to get better economy in the comsumption of fuel. In order to economize fuel, high-pressure steam, with a high degree of expansion and with condensation, was necessary. This led to the practical adaptation, for the propulsion of vessels, of the compound engine—an old invention, which originated with Hornblower in the latter part of the last century, and was afterwards further developed by Wolff. The high degrees of expansion could not be advantageously used in cylinders heated only by the ordinary supply of steam admitted to them for driving the piston; and more especially when that steam was boiled off directly from water without the introduction of additional heat to it after its evaporation. The knowledge of this, which was derived through important advances made in thermo-dynamic science, led to the introduction into ordinary use in steam navigation of steam-jacketed cylinders, and to the ordinary use also of superheated steam. With increased efforts towards economy of space in the hold of the ship, which became the more essential when very long voyages were to be undertaken, and with the new requirement of greatly increased pressure in the steam, the old marine boilers, with their flues of riveted plates, were superseded by tubular boilers more compact in their dimensions and better adapted for resisting the high pressure of the steam. In connection with these various changes, the old difficulty of the growth of the stony incrustations in the boilers became aggravated rather than in any way diminished. As the only available remedy for this, there ensued the practical development and the very general introduction of the previously known, but scarcely at all used, principle of surface condensation instead of condensation by injection. A supply of distilled water from the condenser is thus maintained for feeding the boilers, and incrustations are avoided. The consumption of coal is often found now to be reduced to about 2 lbs. per indicated horse-power per hour, from having been 4 or 5 lbs. in good engines in times previous to about twenty years ago.

Before the times of ocean telegraph-cables, little had been done in deep-sea sounding; but when the laying of ocean cables came first to be contemplated, and when it came afterwards to be realized, the obtaining of numerous soundings became a matter of essential practical importance. In the ordinary practice of deep-sounding, as carried on both before and since the times of ocean telegraph-cables until a year or two ago, a hempen rope or cord was used as the sounding-line, and a very heavy sinker—usually weighing from 2 to 4 cwts.—was required to draw down the hempen line with sufficient speed, because the frictional resistance of the water to that large and rough line moving at any suitable speed was very great. The sinker could not be brought up again from great depths, and arrangements were provided by means of a kind of trigger-apparatus, so that when the bottom was reached the sinker was detached from the line, and was left lying lost on the bottom, the line being drawn up without the sinker, but with only a tube of no great weight, adapted for receiving and carring away a specimen of the bottom. For the operation of drawing up the hempen line with this tube attached, steam-

power has been ordinarily used, and practically must be regarded as necessary.

A great improvement has, within the last two or three years, been devised and practically developed by Sir William Thomson. Instead of using a hempen sounding-line, or cord of any kind, he uses a single steel wire of the kind manufactured as pianoforte wire. He has devised a new machine for letting down into the sea the wire with its sinker, and for bringing both the wire and the sinker up again when the bottom has been reached. With this apparatus, in its earliest arrangement, and before it had arrived at its present advanced condition of improvement, he sounded, in June, 1872, in the Bay of Biscay, in a depth of 2700 fathoms, or a little more than 3 miles, and brought up again his sinker of 30 lbs. weight after it had touched the bottom; and brought up, also, an abundant specimen of ooze from the bottom, in a suitably arranged tube attached at the lower end of the sinker.

An important feature in his machine consists in a friction brake arrangement, by which an exactly adjusted resistance can be applied to the drum or pulley which holds the wire coiled round its circumference, and which, on being allowed to revolve, lets the wire run off it down into the sea. The resistance is adjusted so as to be always less than enough to bear up the weight of the lead or iron sinker, together with the weight of the suspending wire and more than enough to bear up the weight of the wire alone. Thus it results that the arrival of the sinker at the bottom is indicated very exactly on board the ship by the sudden cessation of the revolving motion of the drum from which the wire was unrolling. Another novel feature of great importance consists in the introduction of an additional hauling-up drum or pulley, arranged to act as auxiliary to the main drum during the hauling-up process. The auxiliary drum has the wire passed once or twice around its circumference at the time of hauling up, and is turned by men, so as to give the wire extending from it into the sea most of the pull requisite for drawing it up out of the sea, and it passes the wire forward to the main drum, there to be rolled in coils relieved from the severe pull of the wire and sinker hanging in the water. Thus the main drum is saved from being crushed or crumpled by the excessive inward pressure which would result from two or three thousand coils of very tight wire, if that drum unaided were required to do the whole work of hauling up the wire and sinker.

The wire, though exposed to the sea-water, is preserved against rust by being kept constantly, when out of use, either immersed in or moistened with caustic soda. The fact that steel and iron may be preserved from rust by alkali is well known to chemists, and is considered to result from the effect of the alkali in neutralizing the carbonic acid contained in the water, as the carbonic acid appears to be the chief cause of the rusting of steel and iron.

This new method of sounding, depending on the use of pianoforte wire was first publicly explained by Sir Wm. Thomson in the Mechanical Section of the British Association at the Brighton Meeting, two years ago; and in the interval which has since elapsed it has come rapidly into important practical use.

FRENCH PRESERVATION OF TIMBER FROM DECAY.

From "The Building News."

A director of the French dockyards, and inspector of timber for naval purposes, and an officer of the Legion of Honor, ought to have something to say about the preservation of wood which is worth listening to. It appears that it is a fact established by the agricultural statistics of France that the annual consumption of wood in that country considerably exceeds the reproduction, and consequently its preservation for building purposes has now become a question of the very first importance. In short, by the continued impoverishment of the land in that particular, not only are the interests of the agricultural and industrial population immediately affected, but their future requirements compromised and endangered. Very few persons have even an approximate idea of the enormous consumption of timber which takes place annually in France. It is generally believed that the shipbuilders are the principal consumers, and this would be true, to a certain extent, if it only re-

lated to timber of extraordinary or unusual dimensions, but as regards quantity, the consumption for shipping is almost insignificant. M. Burat, Professor of Commercial Statistices in the Institution of Arts and Sciences, does not hesitate to estimate the annual consumption of timber in France in building and manufactures at 353,166,000 cubic feet, to which must be added, 1,059,498,000 cubic feet for firewood, and 529,749,000 cubic feet made into charcoal.

It has long been known that France is in a bad way so far as timber is concerned, and the scarcity of coal, and the consequent use of timber for firewood, completely shuts her out from supplying England with wood, which she might do in course of years. For their own sakes it is to be regretted that the landlords object to having timber round their fields, and to replacing the timber they cut down. No one (who quite understands the timber trade) wants that agricultural lands should be taken from the plough to turn into forest lands, but a judicious cultivation of what may be called "building trees" will always pay, and not impoverish the corn or other cereal power production of the estate. M. De Lapparent, aware of the scarcity, naturally seeks a remedy in making timber more durable by artificial means. Immersion in water is no doubt a beneficial process for timber to undergo, but how long should it remain under water in order to get rid of its sap, or of as much of it as possible? Evelyn says that a fortnight in river water is sufficient. M. De Lapparent recommends one year in river water; two years in fresh water frequently changed; and three years in brackish water, which should always be changing.

At the close of these several periods, the boards intended for planking should be taken out to be in store, or they might be left to season themselves naturally for two years at least before being worked up. As to the rough ribs, seasoning in store would be totally sufficient, and it would require, after shaping but before putting together, to subject it to an artificial seasoning. There have been many plans of this description in use for some time in France and England, but they have only been applied to wood of moderate thickness, such as boards, flooring, and wainscoting. The plan adopted in London is the injection by means of a ventilator of hot air into the drying stove where the wood is placed; by this the temperature is gradually and gently raised until it reaches boiling heat. But as wood is one of the worst known conductors of caloric, if this plan is applied to large logs, the interior fibers will retain their original bulk, while those near the surface have a tendency to shrink, the consequence of which would be cracks and splits of more or less depth.

M. Guibert, of Touraville, near Cherbourg, has taken out a patent which consists of filling the drying stove with smoke produced by the distillation of certain combustible matters, such as sawdust, waste tan, smith's coal, &c. By means of a ventilator ingeniously arranged, a rotatory movement round the logs is given to the smoke, so as to obtain an average uniform temperature in every part. By this plan, as the distillation of combusti les is always attended with a considerable discharge of steam, all cracks and splits appear to be prevented. In this factory, the author referred to has seen a great number of boards prepared by this method, and all perfectly sound.

Messrs. Légé and Fleury Pironnet have invented an apparatus for the injection of sulphate of copper into beech and poplar. If the wood is only required to be seasoned, a warm current of air is substituted for the liquid, and without doubt this process of seasoning would be the quickest, and we should avoid the cracks and splinters always produced when dry and hot air only are applied. The great cost of the apparatus, and its complicated details, are, however, a drawback.

Charring timber is an excellent mode of preservation, and Lapparent has an apparatus for this object by the use of gas. The results obtained from experiments at the gasometer at Cherbourg, with the aid of a meter, and using a jet of average force, were:—1st. Consumption of gas about 200 litres per square meter, at 200 gallons per 10 square feet of carbonized surface. 2nd. Workman's average day's work of 10 hours would carbonize 440 square feet. 3rd. One workman is sufficient for bellows supplying two jets of gas. At full work the expense would not exceed 1½d. per 10 square feet. The operation can be facilitated by smearing, in the first instance, the surface of the timber with a little tar, and with the following advantages:—1st. The carbonization of the cracks is facilitated.

2nd. It prevents the the timber being too suddenly affected by the heat of the gas, which causes it to split. 3rd. It prevents the cracking and splintering off of little ignited particles. Without going to the length of saying that any means of producing indestructible timber are here propounded, still there is something worth remembering in every line. If the results of recent experiments in this country are confirmed, we shall be in a far better position than our French neighbors, and it is to be sincerely hoped that the results will be proved to be established facts, for it will effect a revolution in the building trade, provided the process is inexpensive. In the mean time, and with the recent experience of disasters occasioned by the imflammability of timber and other causes, any contribution which tends to throw any light at all on the means to be pursued towards its preservation is very welcome.

NOTE-BOOK MEMORANDA FOR RAILROAD BRIDGE CALCULATION.

By E. SHERMAN GOULD, C. E.

Written for Van Nostrand's Magazine.

The following is an attempt to establish the calculation of strains in straight trusses, upon a few simple principles, the application of which will, it is believed, solve expeditiously and directly all cases of this very interesting problem.

PRINCIPLES.

1. The action of the panel weights of both truss and load, is concentrated at the apexes of the web members.

2. The strain on the chords is maximum when the truss is entirely covered with the rolling load; the strain on any tie and corresponding strut is maximum when it and the ties between it and the farther abutment only are loaded.

3. The vertical strains, both fixed and rolling, and under all circumstances of loading, both uniform and partial, are transmitted in proportional parts to the abutments.

4. All vertical strains passing through web members toward the same abutment, are of the same character, *i. e.*, all compressive or all tensile, while vertical strains passing through web members to opposite abutments are of opposite characters and exercise upon such members both compression and tension, and the actual strain upon such members is the algebraic sum of the two strains.

5. The proportional part of the weight sustained by any given tie which travels to the nearer abutment exercises a tensile strain upon all ties and a compressive strain upon all struts between it and that abutment, while the proportional part travelling to the farther abutment, exercises a compressive strain upon all ties, and a tensile strain upon all struts between it and the centre of the truss. From the centre to the farther abutment the previous character of strains is resumed, and the ties are strained in tension and the braces in compression.

Note.—When the truss sustains only its own weight, or is uniformly loaded, each tie and strut transmits a strain equal to the whole weight upon it to the nearer abutment. This is because the proportional parts travelling to the farther abutment are compensated by equal and opposite parts on the other side of the centre of the truss.

ELEMENTS REQUIRED.

L = length of truss, in panels.
D = depth of truss, in panels.
W = panel weight of truss.
W' = panel weight of load.
$W'' = W + W'$.

$$\text{tang. } \theta . W'' = \frac{W''}{D}$$

$$\text{sec. } \theta = \frac{\sqrt{1 + D^2}}{D}.$$

Note.—θ = angle which sloping members make with the vertical.

PROCESS OF CALCULATION.

1. Make a sketch of one-half of the proposed truss. It had better be drawn accurately to scale.

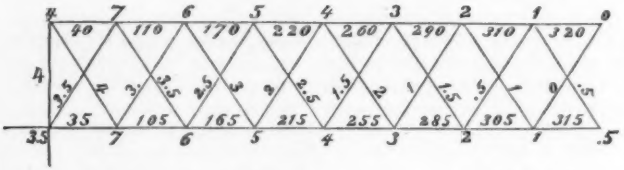
2. Write the coefficient of the panel weight on each tie, directly and transmitted upon such tie and its corresponding strut, commencing at the centre. Add the

coefficients of each pair of sloping members meeting at a common apex, and write the sum at such apex. If only one member is sloping, write its coefficient only at the apex.

3. Obtain the maximum horizontal strain in each panel, beginning at the abutment, by multiplying tan. $\theta \times W''$ by the coefficients of the apexes, and adding the results and writing them on each panel length.

4. Obtain maximum vertical strains by (*a*) tabulating the strains in each tie and strut when under truss weight alone, multiplying for this, W by the co-efficient marked on each tie and strut, and (*b*) by conceiving the whole truss to be covered with the rolling load (LW′) and this weight then removed panel by panel from the abutment to the centre of truss, tabulating successively the strain from rolling load in each tie and its strut as it becomes the last in the loaded segment. This is done by making the number of panels in the loaded segment which the tie under calculation closes, the first term of a decreasing series of which the number of systems in the truss (one, two, etc., according as the truss is a simple, double, etc., truss) is the ratio. The sum of this series, multiplied by W′ and divided by L gives the maximum vertical strain from rolling load, for the given tie. This strain, added to that, already tabulated, of

FIG. 1.



truss load, gives total maximum vertical strain, and being multiplied by sec. θ, gives actual maximum strain in ties and struts.

These strains may be checked by recollecting that the maximum strain on any tie is equal to the strain on that tie when the whole truss is covered with the rolling load, *plus* the strain sent through it to the farther abutment by the rolling weight of the same system between it and the nearer abutment.

APPLICATION.

Let Fig. 1 represent half of a double Warren truss, of the following elements:

L = 16.
D = 1 5.
W = 5 tons.
W′ = 10 tons.
W″ = 15 tons.
tan. $\theta \times W''$ = 10 tons.
sec. θ = 1.2.

Operating as described above, we get the

TABLE 1.

1. No. of Tie and Strut.	2. W	3. W′	4. W + W′	5. W″	6. +	7.	8. × Sec. θ.
1	20	40	60	60	.....	60.	72.
2	17.5	35.	52.5	52.5	.....	52.5	63.
3	15.	30.6	45.6	45	0.6	45.6	54.7
4	12.5	26.25	38 75	37 5	1 25	38.75	46.5
5	10.	22.5	32.5	30.	2 5	32.5	39.
6	7.5	18.75	26.25	22.5	3.75	26 25	31.5
7	5.	15 6	20.6	15.	5.6	20.6	24.7
8	2.5	12.5	15.	7.5	7.5	15.	18.

coefficients marked on the ties and struts in the sketch, and from there the apex coefficients and horizontal strains marked on the panel lengths of upper and lower chords.

In calculating the maximum strains in struts and ties, we use the decreasing series mentioned above, the ratio being 2, that being the number of systems in the truss. Thus, supposing the 12th tie was under calculation, we should have:

$\frac{W'}{L}(12 + 10 + 8 + 6 + 4 + 2) = 26.25$ tons.

This added to 2.5 W = 12.5 tons, gives 38.75 tons for total maximum vertical strain on this tie and corresponding strut. To apply the check we have on this tie, when the truss is fully covered with rolling load, 2.5 W″ = 37.5 tons. The apex between it and the nearer abutment sends $\frac{2}{12}$ W′ = 1.25 tons through it to the farther abutment, making a total of 38.75 tons, as above.

We have, therefore, the following table of strains on ties and struts, beginning at the abutment. (See Table 1.)

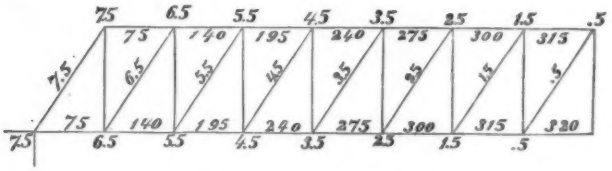
The 5th and 6th columns contain the check calculation, the result of which, in the 7th column, is the same as that of the first calculation in the 4th column. The 8th column shows the actual strain, obtained by multiplication by sec. θ.

The numbers in the first column refer to the ties, counting from the abutment, and apply also to the corresponding struts. The first strut, however, being vertical, does not require the multiplication by sec. θ.

If the truss had been simple, *i. e.*, containing only one system of bracing, the calculation would have been similar, as it would also be, did the truss contain 3 or more systems.

As an example of a simple system of bracing, we have in Fig. 2 the half of a Howe truss; the elements being the same

Fig. 2.



as before; the coefficient and horizontal panel strains are shown in the sketch. The following table shows the maximum vertical strains, observing that the ties, being vertical, should not have their strains multiplied by the secant. Also, that the strain on the centre strut must be doubled for the centre tie, as it (the tie) sustains a whole panel weight, which is divided between the two centre struts. The coefficients are marked on the struts alone, as the ties have no horizontal components.

Table 2.

1.	2. W	3. W′	4. W + W′	5. W″	6. +	7.	8. × Sec. θ.
1	37.5	75.	112.5	112.5	0.0	112 5	135.1
2	32.5	65.7	98.2	97.5	0.7	98.2	117.8
3	27.5	56.9	84 4	82.5	1.9	84 4	101 4
4	22.5	48.8	71.3	67.5	3.8	71.3	85.6
5	17.5	41.3	58.8	52.5	6 3	58.8	70.6
6	12.5	34 4	46 9	37 5	9.4	46 9	56 4
7	7.5	28.2	35.7	22.5	13.2	35.7	42.8
8 {	2 5	22 5	25.	7.5	17.5	25.	30.
	2.5	.....	27.5	25.	2 5	27.5	

In simple trusses like the Howe, these strains are a little in excess of the true maximum vertical strains, as there is always a half a panel weight of rolling load $\left(\frac{W'}{2}\right)$ acting as a subtractive element, but this is omitted, being an error on the side of safety, to avoid complicating the calculation. It can easily be taken account of if required.

It will be perceived that in order not to complicate the figure in the above example, the counter braces are omitted. As the main office of these members is to stiffen the truss, in which service they sustain an uniform strain of one panel weight of rolling load on each counter, they should be calculated to receive this strain without flexure, in which case they will be probably always more than sufficiently strong to re-

sist any direct shearing strain which may come upon them. For instance, in the present case, let us see what direct shearing strain can come upon the counter brace next the centre—which is the one most strained—when the truss is half covered with the rolling load, which is the condition entailing the heaviest shearing strain on the counters. By summation of series, we will find a compressive strain upon it of $28\frac{W'}{L} = 17.50$ tons, and a tensile strain of $\frac{W}{2} + \frac{W'}{4}$ (the rolling load reaching only to the centre, leaves only $\frac{W'}{2}$ on the centre tie, half of which goes to each abutment) = 5 tons. Total compression 12.5 tons, or only 2.5 tons in excess of the stiffening strain.

In the previous example of a double Warren truss, the greatest shearing strain, under similar circumstances, would come upon the strut at the centre, marked with the coefficient 0. This would sustain tension to the amount of $\frac{W'}{L}16 = 10$ tons, against which there is no compression to set off. We have, therefore, a total of 10 tons tension on this member, just what is called for by the stiffening strain.

The above process of calculation applies to all kinds of straight trusses. The only kind of truss likely to cause any difficulty in its calculation is the Post, and some kinds of multiple lattice trusses. These are sufficiently discussed in No. 39, Vol. VI. of this magazine to render any farther notice of them unnecessary.

The following formulas for strains in straight flanged girders, resting on two supports or abutments, and variously loaded, may be found convenient. Some of them are believed to be new:

W = weight = 10 tons in the examples.
L = length between abutments = 12 ft. in the examples.
D = effective depth, = 1 ft. in the examples.

1*st Case.*—Girder sustaining a single weight, at centre.

Horizontal strain, at centre—

$$S = \frac{W L}{2 D}.$$

At a point distant n from nearer abutment—

$$S = \frac{W n}{2 D}.$$

Vertical strain throughout—

$$S = \frac{W}{2}.$$

2*d Case.*—Girder sustaining weight at a point distant p from either abutment—usually taken from nearer one.

Horizontal strain, at point of application, p—

$$S = \frac{W p}{D L}(L - p).$$

At a point distant n from nearer abutment, p being also counted from nearer abutment.

1*st.* When p and n count from same abutment

$$S = \frac{W n}{D L}(L - p).$$

Ex.—Let n = 2 ft. from left hand abutment.
Let p = 3 ft. from left hand abutment.
S = 15 tons.

2*d.* When n and p count from opposite abutments

$$S = \frac{W n}{D L} \cdot p.$$

Ex. Let n = 2 ft. from right hand abutment.
p = 3 ft. from left hand abutment.
S = 5 tons.

Vertical strain. Let $p' = L - p$. Then vertical strain between point of application and nearer abutment—

$$S = \frac{p' W}{L},$$

and between point of application and farther abutment—

$$S = \frac{p W}{L}.$$

3*d Case.*—Girder covered with uniformly distributed load.

Horizontal strain at centre—

$$S = \frac{W L}{8 D},$$

at a point distant n from either abutment, usually taken from nearer—

$$S = \frac{W}{2 D L}(L n - n^2).$$

Vertical strain at any point distant n from nearer abutment

$$S = \frac{W}{2 L}(L - 2 n),$$

or, if $W' = \frac{W}{L}$ = weight per unit of length of girder—

$$S = \frac{W'}{2}(m - n),$$

m being $= L - n$.

The greatest vertical strain comes on any section of girder when it is only loaded from such section to farther abutment. It then exceeds the strain at such section when under uniformly distributed load by

$$\frac{W m^2}{2L^2}, \text{ or } \frac{W' m^2}{2L},$$

W' being as before $= \frac{W}{L}$, and m being the length of the unloaded segment.

4th Case.—Girder loaded with an uniformly distributed weight W, as in previous case, and also with a single weight, W' applied at a point distant p from nearer abutment as in Case 2. Required, the point of maximum horitontal pressure, distant x from nearer abutment, and amount of strain at this point.

N. B. The point of maximum horizontal pressure is that around which the reactions of the two abutments are equal.

$$x = \frac{L W + 2 p W'}{2 (W + W')}.$$

Let $x' = L - x$. Then

$$S = \frac{x'}{2DL}(LW + 2pW' - Wx')$$

Ex. Let $p = 3$ ft. and $W' = 10$ tons.
Then $x = 4.5$ ft., and
$S = 32.8$ tons.

BUILDING IN CONCRETE.

By W. C. HOMERSHAM, C. E.

From the "Journal of Society of Arts."

In the portion of waste ground near the machinery room, known as the Western Annexe, there are four firms exhibiting buildings of concrete in course of erection. As it is intended to carry on the process of building during the next few months, it is only possible to describe the erections as they now are, and it must be remembered that they are from day to day continually changing.

One exhibitor, Mr. Drake, is building a two-story house 12 ft., 6 in. square in internal dimensions, with walls nine inches in thickness throughout. The walls are at present carried up a few feet higher than the level of the first floor, which is finished off, as also are the stairs leading thereto. The steps are very neatly moulded in concrete, and have much the appearance of having been worked out of sandstone. The concrete in the walls of this building is composed of a compound of Portland cement and selenitic lime, gauged one part of the compound (one-third Portland cement, two-thirds selenitic lime) to seven parts of gravel containing a suitable proportion of sand. The stairs and first floor are made of concrete gauged with pure Portland cement and gravel, in the proportion of one part of the former to five of the latter. In the construction of the first floor one light wrought-iron rolled joist was embedded in the concrete.

Another exhibitor, Mr. Tall, has a house 17 ft., 6 in. by 16 ft., on the plan, in internal dimensions, in about the same stage of erection as the one already referred to. In this structure there are no stairs or means of communication internally between the ground and upper floors. The upper floor is completed, and covers the entire space enclosed by the walls. The underside of the upper floor, that is the ceiling of the ground-floor room, is slightly domed. The walls, which are twelve inches in thickness, and the flooring, are composed of Portland cement concrete, gauged in the proportion of one part of cement to seven parts of hard lumps of burnt clay, technically termed "burnt ballast," mixed with sand, for the former, and in the proportion of one to five of burnt ballast and sand for the latter.

There are also a set of six concrete rooms, erected by Mr. Nichols, for the purpose of testing the stoves sent in for the Society's prizes. Though these were not built specially for purposes of exhibition they may be regarded as giving with the other buildings specimens of this mode of construction. It must be borne in mind that the walls have not been faced, but re-

main in the rough state in which they have left the mould.

A fourth exhibitor, Mr. Lish, is showing a material he calls "Tilo-concrete." In this case a single room with door and window is being built, and the material is concrete faced with tile and terra-cotta mouldings. The tiles are arranged in a supporting frame in their proper position, and concrete filled in behind. They are formed with a dovetail or feather behind, round which the concrete sets and holds them fast. The effect is thus produced of a smooth tiled wall. The cost is stated to be about the same as that of the best brickwork. A principal feature of this exhibit is the method of construction employed. At the commencement of the work "guide screws" (in place of the external uprights now in use) are set in the foundation trenches and "plumbed," when the concrete for foundations is filled in round them; after this material has set, these "guides" are screwed up to receive cross-heads, from which the wall panels are suspended. For building ordinary concrete walls plain wooden panels are used, but when the work has to be faced with tiles a skeleton iron panel is employed with rebated bearers to retain the tiles accurately in position until each day's work has set. When one portion is sufficiently set, by means of screws the panels and the platform which rests on them, and serves instead of a scaffolding, are raised, and the work continued as before.

There is one fact noticeable in all the exhibits in a greater or less degree, and that is the ignorance shown by the constructors of the great strength of concrete to bear strains, tensile and other. There can be no doubt that the insertion of the wrought-iron rolled joist in the flooring, of which a plan is given in the figure, is a source of weakness rather than of strength. Portland cement concrete will not adhere to a surface of iron with anything like the same amount of force that the particles of which it is composed hold to each other. In that building also, which is entirely covered with a domed ceiling in concrete, a mistake appears to have been made. Are walls twelve inches in thickness, and nearly as many feet in height, adapted to take the thrust at the top of a very flat arch? Would not a floor of uniform thickness and containing less material (concrete) have been the stronger? To enable the reader to form an opinion for himself on the subject of the latter question, some facts will be hereafter given concerning the strength of Portland cement concrete. A thorough examination of the structure, of which a plan of the first floor is given in the figure, must alone convince the most skeptical on the point of the great value of concrete in Portland cement as a building material, not only for the walls, but for the flooring of every storey and the roofing of houses of every description. The overhanging corner of the flooring at the well for the stairs, in no way supported from below, is quite firm and free from vibration when walked upon or even when jumped upon by two youths of an aggregate weight of over 2 cwt. The floor is seven and a-half inches in thickness.

From the results of experiments made some years since, it can safely be affirmed that the staging necessary for carrying a concrete floor, in green or wet state, of a room say twelve feet six inches in width, by twenty-five feet or any other dimensions in length, may be struck in a week after the completion of the floor if the concrete be only six inches in uniform thickness, and gauged in such proportions that every cubic yard when *in situ* contains four bushels of cement and six bushels of clean, sharp, silicious sand. One month after the concrete has set, the floor would be capable of sustaining an equally distributed load of one hundred-weight per foot superficial, and twelve months after, an equally distributed load of four hundred-weight per foot superficial. If the thickness of the flooring be increased to twelve inches, and the concrete be gauged as above, a room nineteen feet six inches in width by forty feet or any other dimensions in length, may be covered, with the results as to strength the same as those given for the room twelve feet six inches in width.

The roof of a room twelve feet six inches in width may be formed with a layer of concrete four inches in thickness, and that for a room twenty feet in width need not exceed nine inches in thickness. Concrete in Portland cement is admirably adapted for the construction of roofs of buildings; concrete is far less pervious to water than the best brickwork, and when its surface is rendered with a thin coating of compo, gauged one of Portland cement to one of sand, it is perfectly impervious to damp, though it be kept covered with water. The

fact may not be generally known that Portland cement compo has not that tendency to peel off when on concrete in cement, which impairs its efficacy as a facing for brickwork. This is accounted for partly by the surface of concrete (being rough) forming a capital key for the compo, but principally by the far more important fact, that there is no damp in Portland cement concrete after it has thoroughly set. Brickwork absorbs and retains moisture, which, being acted upon by frost, swells, and lifts the plaster from the smooth surface of brickwork. Such cannot be the case with concrete.

Not only is a coating of Portland cement compo valuable on the top surface of the layer of concrete forming a roof, as a protection against damp, but it forms an excellent surface for the flooring of a building. A surface of Portland cement compo resists the action of the tread quite as well, if not better, than some of the superior sorts of stone used for making steps.

The public might here derive great advantage from the practical manner in which the four exhibitors have explained their respective ideas on the subject of building in concrete. The houses they are in the act of constructing will doubtless do much during the season to convince many a visitor that it is possible to construct not only cottages but mansions the most extensive in concrete. A structure composed solely of concrete in the stairs, floors, and roof, as well as walls, is practically monolithic, and not only perfectly water and damp proof, but as nearly as can be conceived proof against the ravages of that all-devouring element—fire. By forming the division walls between the various rooms, of Portland cement concrete, each room will be rendered sound-proof, concrete being an excellent non-conductor of sound. The concrete for the walls of buildings need not contain more than three bushels of Portland cement and six bushels of sand per cubic yard. In critically examining the structures in concrete being constructed in the Western Annexe, the visitor must not lose sight of the fact that the exhibits are made by firms desirous of calling the attention of the public to particular forms of apparatus for facilitating construction in concrete, and not by architects desirous of ventilating their professional abilities in the art of adapting a comparatively speaking novel material to building purposes. Had the case been otherwise, there is no reason no doubt there would have been no drawback to the efforts made by the exhibitors in an architectural point of view, such as there is at present. The surfaces of the walls and ceiling of some of the structures are in the rough state, and exemplify the truth of that which has been stated above concerning the excellent key that can be left on the surface of concrete for a rendering of compo. The inner and outer surfaces of the walls, etc., of the building erected by one of the exhibitors are finished off, and have a very neat and clean appearance, though it must be owned the sight reminds one too much of our suburban builders' style of architecture. The writer has seen some very handsome facework on concrete made by imbedding split flints therein, with the split face exposed. How many lovers of good architecture have walked miles to examine a particularly fine piece of flintwork, such as is to be seen at St Augustine's Monastery, Canterbury, and in many other old buildings in that city? Why should not we of the present generation attempt at any rate to vie with our ancestors in this particular art, if such a use of the term may be permitted? In chalk countries where suitable flints are plentiful, field laborers are generally to be found who have been taught the knack of splitting flints. In places where such is the case, a facing of split flints exceeds but little in cost that of forming a face of compo.

For cottages and outhouses, etc, a very clean and neat face may be given to the walls and ceiling by placing a course of pebbles on the exterior surfaces. The pebbles when their outer surfaces have been freed from any compo that may have passed between them during the time of the setting of the concrete, form a surface that is agreeable to the sight and capable of receiving any amount of relief or ornament in compo, the surface being so admirably adapted to key the same. Little more need here be said on the subject of embellishment in concrete, as there are many members of the engineering, and doubtless of the architectural profession also, who could and would design and build a structure wholly in concrete that would prove as pleasing to the great majority of persons of taste in such matters as if it were constructed with brickwork and stone.

Notwithstanding that the exhibits prove the great strength of Portland cement con-

crete, they present no data on which to calculate the exact strength of any particular piece of flooring or wall. Mr. John Grant, C. E., of the Metropolitan Board of Works, investigated the subject of the properties and strength of Portland cement, and has given the valuable and thoroughly reliable results to the world in papers read before the members of the Institution of Civil Engineers. The first paper was read by Mr. Grant in the session 1855-6, and will be found in the 25th volume of the Minutes of Proceedings of the Institution of Civil Engineers, and a second paper was read in the session of 70-2, and will be found in the 32d volume of the Proceedings.

The following table gives the results of experiments made by Mr. Grant on the tensile strength of Portland cement weighing 112 lbs. per imperial bushel, gauged neat, and also with various proportions of clean, sharp, silicious and other sand, after having been kept under water respectively one week, one month and twelve months, the particulars of which will be found in the papers :—

TABLES OF THE TENSILE STRENGTH IN POUNDS AVOIRDUPOIS OF SECTIONS (1½ IN. × 1½ IN. =) 2¼ INCHES IN AREA OF PORTLAND CEMENT, WHEN GAUGED WITH

IN THE PROPORTION OF	CLEAN, SHARP, PIT SAND, AFTER			CLEAN THAMES SAND, AFTER			LOAMY SAND, AFTER		
	One week	One month.	One year.	One week.	One month.	One year.	One week.	One month.	One year.
Neat	445	680	1,076	.....	.....	.....	.....	.....	.....
1 to 1	152	326	796	97	309	700	114	275	645
1 to 2	64	166	607	52	123	458	53	130	533
1 to 3	44	91	424	27	58	321	21	68	358
1 to 4	22	71	318	.....	32	222	.....	60	244
1 to 5	.....	49	216	.....	21	122	.....	31	166

From the same authority the materials are drawn for the following :—

TABLE OF THE COMPRESSIVE STRENGTH IN TONS OF SURFACES (9 IN. × 4¼ IN. =) 38¼ IN. AREA OF

IN THE PROPORTION OF	PORTLAND CEMENT WHEN GAUGED WITH CLEAN, SHARP, PIT SAND, AFTER		
	Three months.	Six months.	Nine months.
Neat	65	92	102
1 to 1	43	59	78
1 to 2	34	47	62
1 to 3	24	37	41
1 to 4	23	31	38
1 to 5	16	26	29

It is stated also in the same papers that the crushing weight of a good stock brick laid on the flat (area about 9 in. × 4¼ in. =38¼ in.) is 34 tons, that of a wire-cut gault brick 33 tons, of a compressed gault brick 35 tons, of a brimstone Suffolk brick 44 tons, and that of a fire-brick 63 tons. A fire-brick though it offers nearly double the resistance to a crushing force that stock brick does, is only as powerful to resist a compressive strain as is a similar brick of Portland cement gauged with double its bulk of sand, at the end of twelve months.

The transverse strength of fixed slabs of concrete in Portland cement may be calculated by the following formula, when the concrete has been made of first-rate materials and thoroughly incorporated with four bushels of cement of the first quality, and six bushels of clean, sharp, silicious sand, per cubic yard.

Let A represent the area of the transverse section of a slab, and D the thickness thereof, both in inches, L the length of span in feet, and W the equally distributed load in cwts. that will cause a rupture in the concrete at the end of a week, after the concrete has been left to set, then

$$\frac{A\,D}{4\,L} = W.$$

The constant is 1-6 in place of 4 for the strength at the end of a month, and 0.56 for the strength at the end of a year.

Example.—What amount of uniformly distributed load will a slab of Portland cement concrete (gauged with 4 bushels of cement, and six bushels of sand per cubic yard), 15 ft. in length by 1 ft. in width, and 6 in. in thickness, bear at the end of a

week, a month, and a year when fixed on bearings 13 ft. apart.

$$\text{Area } (12 \times 6 =) \frac{72 \times 6}{4 \times 13} = 8.3 \text{ cwts. at the end of a week.}$$

$$\frac{72 \times 6}{1.6 \times 13} = 20.76 \text{ cwts. at the end of a month.}$$

$$\frac{72 \times 6}{.56 \times 13} = 59.34 \text{ cwts. at the end of a year.}$$

The weight of the concrete itself often forms an important item in the amount of the load to be carried, particularly when the length of the span or opening is considerable.

Concrete varies considerably in density, but in calculating the amount of the weight as a quiescent load, it will suffice for all practical purposes to take the weight of a cubit foot at 1.2 cwt., which is equal to 0.1 cwt. per foot superficial for each inch in thickness of a slab of cement.

The weight of a six-inch slab of concrete, 1 ft. in width by 13 ft. in length (between the bearings) so calculated is ($1 \times 13 \times .6 =$) 7.8 cwt.

By the foregoing calculations it appears that such a slab after it has been made a week is capable of sustaining an uniformly distributed load of 8.3 cwt., or .5 cwt. in excess of the quiescent load in the shape of the weight of the concrete itself. It follows that the supporting staging may be struck with safety at the end of a week.

At the expiration of one month the transverse strength of the slab is increased so greatly as to enable the slab to bear a uniformly distributed load of 20.76 cwt. in the gross or (20.76—7.8=)12.96 cwt., independent of the weight of the concrete. Again, at the end of a year the transverse strength is further increased, and the slab will sustain 59.34 cwt., uniformly distributed in total, or (59.34—7.8=) 51.54 cwt., independent of its own weight. In other words, a six-inch slab of Portland cement concrete, 1 ft. in width, spanning an opening of 13 ft., is capable of sustaining, after it has been made twelve months, an uniformly distributed load equal to nearly 4 (3.96) cwt. per ft. superficial. To attain uniformity in the strength of concrete, so essential in the construction of monolithic floors and roofing, it is advisable to adopt the French system of mixing, that is, gauging the cement and sand into a compo in the first instance, and then adding clean-washed shingle or burnt ballast, or a mixture of the two, in the proportion necessary, according to the nature of the work to be executed.

Great attention must be paid to the quality of all the materials used in making concrete in Portland cement, even to the water, which should be perfectly clean. The weight of the cement per imperial bushel should not exceed 116 lbs., or be less than 112 lbs., when dropped into the measure from a board fixed, say 2 ft. above the top of the measure. The sand should be rather large-grained, sharp, silicious sand, and must be washed perfectly free from loam or other extraneous matter. The shingle also should be washed free from particles of sand as well of loam and other foreign matters. The thorough incorporation of the cement and sand is facilitated by mixing them dry under edge-runners for a period of five minutes for each portion of sand there is to one of cement before adding the water; thus, in the concrete for the floors, the writer would recommend the compo to be gauged one and a-half of sand to one of cement, therefore it should be mixed dry under edge-runners for ($5 \times 1\frac{1}{2} =$) $7\frac{1}{2}$ minutes. In the concrete for walls if the compo be gauged at two of sand to one of cement, the time of mixing dry should be ($5 \times 2 =$) 10 minutes; and when the nature of the work to be executed is such as to permit of the compo being gauged three of sand to one of cement, then the time must be extended to fifteen minutes.

The prime cost of concrete varies considerable according to the site on which it is used and the nature of the work to be executed. Thick walls of a building in concrete, as in brickwork, are less expensive per cubic yard to construct than walls that are thin. Boundary or garden walls may be constructed with safety of concrete gauged in such proportions that each cubic yard contains only two and a-half bushels of Portland cement and seven bushels of sand.

The public have the advantage of seeing in the exhibits two distinct materials used to form the body of the concrete—gravel and burnt ballast. Both make equally good and strong concrete; but perhaps concrete of burnt ballast is to be preferred for the construction of flooring and roofs. It is both lighter and better adapted to resist the action of fire than concrete of gravel.

The first cost of cottages in concrete, with concrete stairs, floor, and roof, is from 30 to 40 per cent. less than a building of brickwork, with slate roof and timber floors. Besides first cost, the cost of maintenance has to be taken into consideration in determining the actual value of any property. This is entirely on the side of concrete as a building material. There have been many cases where far larger sums have been expended, and fairly expended, in breaking up a piece of good concrete in cement than it cost in making.

To enable the reader to form an approximate idea of the cost of Portland cement concrete *in situ* in a cottage or two-story building, it may be mentioned that the cost for labor of all kinds should not exceed 2s. 9d., but say, 3s. per cubic yard or £1 14s. per rod. The cost of Portland cement may be taken at 2s. 6d. per bushel delivered on to the works, including the cost of testing. The paper read by Mr. Grant before the members of the Institution of Civil Engineers (see 26th volume of the Proceedings) concludes with a most needful warning from the author against the use of Portland cement, by any engineer or architect who is not prepared to take the trouble and incur the expense of thoroughly testing every bulk of cement on its delivery on the site of the works.

First-class concrete for floors and roofs, as has been shown, requires 4 bushels per cubic yard, or 45$\frac{3}{4}$ bushels per rod, making the cost for Portland cement 10s. per cubic yard. or £5 13s. 6d. per rod.

Concrete of the second class, for walls of buildings, contains 3 bushels per cubic yard, or 34 bushels per rod, the cost of which is respectively 7s. 6d. and £4 5s.

In garden walls and steps for stairs the cost of the cement is only 6s. 3d. per cubic yard, or a little less than £3 10s. per rod. Two and a-half bushels per yard, or twenty-eight bushels and a third per rod, are thus all the cement that is required.

Should there be a pit of good clean gravel handy to the site of the works, to produce the necessary quantities of shingle and sand, the cost of the gravel to make one cubic yard of concrete should not exceed, say 15d., including carting, screening, and washing, that is, 14s. 2d per rod. When the cost of getting first-class gravel on to the ground exceeds 3s. or 3s. 6d. for the quantity necessary to make a cubic yard of concrete, it may prove more economical to burn clay from the foundations of the buildings, etc., and make burnt ballast.

The minimum cost of burning ballast when clay fit for the purpose is found on the site of the works may be put down at 3s. per cubic yard, including the cost of labor in sifting and washing, but not of providing the necessary quantity of water. The quantity of water required for washing and soaking burnt ballast is about 20 gallons per cubic yard, or a ton weight per rod. One half that quantity will suffice for washing good gravel, containing the proper proportion of clean sharp silicious sand; such only should be used in making concrete. The quantity of water requisite for gauging the compo is about three gallons per bushel of Portland cement and one gallon per bushel of damp sand.

This case will prove to be very exceptional where the cost of Portland cement concrete *in situ* in a building proves to be on the average less than 10s., or more than 16s. per cubic yard, *i. e.*, £5 13s. 6d., or £9 1s. 6d. per rod.

In Room 22 of the International Exhibition will be found samples of Portland cement and of blocks of compo thereof gauged neat, that have been tested, and when broken the amount of the tensile strain which broke it may be seen marked on each.

The "testing machine for cement," exhibited in the same room (No. 5,719), is by no means satisfactory; it compares very unfavorably with the excellent, delicate, and well-adapted instrument used by Mr. Grant in making all the experiments of which he gives the particulars in his papers before referred to. In testing with an instrument of the pattern adopted by Mr. Grant, the block of compo cannot be subjected to any amount of jar or vibration, and the exact breaking weight to a pound is registered.

In Room 22 will also be found exhibits of the Selenitic Cement Company (limited) and of that made by Alex. McClean and Company. They both deserve the careful consideration of any person interested in building operations, and particular of those contemplating building in concrete. The "superfine quality" cement exhibited by the latter is very white, and takes a very high polish, as it is exemplified by some of the articles in the exhibition.

A FEW OF THE ESTHETIC PRINCIPLES OF ARCHITECTURE.

By C. A. EVANS, C. E.

Written for Van Nostrand's Magazine.

The principal object of architecture is to build well as regards stability and convenience. Still it extends beyond this point into the domain of taste, and aims at giving a suitable expression to a contemplated structure. A consideration of some of the principles in this latter branch of the art, will form the subject of the following remarks.

Evidently the expression desired must be varied to suit each class of buildings. A theatre should express in its style the festivity to which it is devoted, a house of legislation should appear grand, a dwelling polite, a villa inviting. Such expressions are to be attained, however, without sacrifice of either strength or convenience, and without the introduction of unnecessary features. Success depends mainly upon the education given to the taste; which is most effectually acquired by means of an enlightened observation through art and nature. The rarity of its possession will account for the many failures to produce fine buildings. Sometimes false ideas of what constitutes the skill of an artist, contribute to the same unhappy end. For instance, it is very generally regarded as an index of architectural talent, the ability to make fanciful designs which shall not resemble, either in outline or details, any other structure previously erected. These designs are most always pleasing on paper, it is true; but afterwards, when carried out in stone, they do not give as much satisfaction. As in literature, such exuberances are indicative of more vigor of imagination than correctness of taste. Thought plays in them a subordinate part to fancy, which inspires the whole. The severely pure, in which genius appears at times a little rough, but always very grand, where the art is too deep to be seen, and, still, too powerful not to be felt, is preferable by far to easier and gaudier work.

Taste then, upon which so much depends, is, to a great extent, a child of circumstances. These are greatly determined by peculiarities of race, which in turn are influenced by climate; so that there exists no one standard by which to form taste. Yet it is subject to law, however powerful the influences which tend to modify it, however contrasting the various shades of its character. Who that looks on Grecian art can consider its efforts as either fitful or accidental in their production? The leading principles in these works were derived from nature. The Greeks allowed her to speak; their acts were guided by her voice until their country fell, and had fulfilled its destiny. They studied nature, not as we, by dissecting, classifying, pondering over her economy, but by viewing her with eyes and feelings of artists. The drooping leaf, the lion's mien, the human form, each was to them full of expression. Not content, however, with simply contemplating her beauties, they roused their minds to the search of the principles by the aid of which she gave character to her productions. And they succeeded better both in discovery and applying them than any other race of which record remains. In modern times painters have, as a rule, followed nature more closely than architects. This will appear when we consider that the first works with the concrete and the abstract united, while the second does not, and must separate the one from the other in order to utilize the abstract.

Such a separation having been always attended with great difficulty, and much patience, architects have become accustomed, and indeed, in some measure forced to rely almost exclusively upon the eye and fancy. Though these are guides easier to follow, yet are they also inferior to the teachings of nature. Sometimes from education, often from prejudice, many doubt that architecture is susceptible of any method of treatment different from this usual one. A few others have regarded economy and convenience as the sole objects to be kept in view when designing. As too expensive, therefore, they have banished the Ionic and Corinthian capitals from the art. But a system of architecture which will not permit these capitals being used is indicative of ideas too extreme to find support in those who cling to the chaste and the beautiful. Economy and convenience are fundamental principles in architecture, and the direction in which they point is the correct one. Yet it is not natural for attention to be concentrated ex-

clusively on utilitarian points. The mind seeks instinctively to adorn what it produces. With better judgment, and in imitation of the ancients, others again have applied themselves to the task of investigating the various means which nature employs to give expression.

Foremost among the results of their labors we may notice that, in animals, the idea of str ngth is conveyed to the mind mostly by angularity. When this principle is applied, many sharp contrasts of light and shade are produced. Curvature and roundness on the contrary, are expressive of elegance; and shade, in this case, passes into light by gradation. Reflected curves, so extensively found in the female form, are symbolical of the highest beauty. Round bodies, like the trunks of trees, have an air of strength only when their surfaces are roughened. Hence, in obedience to the foregoing principles, whenever it is desired to express strength, angularity must be found among the characteristics introduced. This object is attained in a design, but only partly, by making the voids and projections rectangular in elevation. In spanning openings with arches their shape is softened; there is gained in elegance what is lost in power. Angularity, though the main characteristic of strength, yet, alone, is not sufficient to denote it fully, and must be combined with breadth. A different practice, by combining height with angularity, leads to majesty; while height with roundness gives elegance in its greatest intensity.

These principles are true to nature. We all recognize that the pine has a different aspect from the oak. The one is tall and majestic; the other broad and strong. The pine stately bends to the breeze; the oak staunchly resists the tempest. And, among the flowers, does not the lily owe its elegance to its slender proportions? In the animal, as in the vegetable kingdom, the same principles reign. The deer we take as an emblem of beauty, and the lion as a representation of power.

According to the preceding, therefore, if we wish to give either to a building, or to a detail a character of strength, we must, besides introducing angularity, intensify breadth. The Greeks understood well this principle, and applied it extensively. They appreciated the opposite principle also, of uniting height and curvature where elegance was desired, though they confined its application almost exclusively to details. There are many features in which height will necessarily exceed breadth. Still, as such features are common to buildings of different characters, variations in their proportions may always be practised, so as to show conformity with the change of expression in the buildings. Columns were thus treated in Grecian architecture; and subject to the same treatment are also balustrades and openings.

Height and intense angularity, when appearing in large features, are productive of a severe majesty of expression. It is evident that no majestic appearance can be given to small details, though proportions in these similar to those in the large features, will be conducive to unity of design, and enhance the effect of the taller masses. By severe angularity is to be understood the existence of right and acute angles, in distinction to obtuse angles. The latter are appropriate to forms less severe, being intermediate in severity between squareness and roundness.

Projection is regulated in severity by the angle at which it juts from the wall. Though most usually this is a right angle, yet, at times, projecting masses make obtuse angles with the walls from which they start. Supported by corbelling, projections lose their boldness to a certain extent, but present, in compensation, a more elegant appearance. The character of the corbelling should be in harmony with that of the projection. Thus, a light corbelling should not support a heavy projection; neither should the corbelling be more massive than the projection. The mass beneath should not pretend to sustain completely the mass above; its office being simply to aid the projection in supporting itself.

Angularity finds its application, to a greater or smaller extent, in all styles of architecture. In some styles it is very decided. To cont nue angularity to the top, to finish everything square, is the peculiarity of Norman architecture, and the cause of the strength expressed by it. This character of strength is intensified, besides, by monotony in wall, tower, and battlement, and by a regular, though broken elevation, the various portions of which are different in height. In the portions so separated, as well as in the whole mass, breadth must preponderate. This is very essential. But whatever be the other characteristics of a style, angularity, or contrast of light and

shade, should never be wanting. Such contrast is the fundamental esthetic principle of architecture. Gradation follows, and softens, at suitable points, the quick transitions from light to shade. It thus introduces elegance, and serves to adorn strength. There are, besides contrasts of light and shade, contrast in size, and contrast in form. We find also gradations of these. But contrast demands two divisions; gradation at least three. Two things may be contrasted, but three are necessary to express gradation.

Upon the principle of gradation depends the practice of placing the lighter forms above the graver. A hexagonal feature is put above a square one, and a cylindrical feature higher than a hexagonal one. Hence the lower portions of a building should present none but grave forms, while in the upper parts the lighter forms may be introduced. Hence the greater number of mouldings are massed in the frieze and cornice, and prohibited almost entirely in the large features at the base. In the Norman style not much gradation can be found, and in some bad examples there is a sudden change from one extreme to the other. But Romanesque architecture presents very often in belfries and towers, gradations of size and form exceptionally well managed. Grecian architecture offers as much angularity and monotony as the Roman, yet gradation is introduced at the same time; for which reason it does not express the immense strength of the feudal piles. Good examples of a partial gradation may be noticed in Italian belfries, made solid at the base for one or two stories, openings are next introduced commencing with a single one and increasing them in size and number as their location becomes higher. So far only is the gradation carried; not beyond masses of light and shade. A more complete gradation would be, to cause the stories to soften in form and change in magnitude with their elevation above the ground. These modifications, however, while producing more beauty, would destroy considerably the majestic appearance of the belfry, due to the long vertical lines extending from the foundation to the roof. The square towers of the Gothic style, when they do not change in shape upwards, are lower than the Italian, and, therefore, have an aspect of great strength and massiveness.

The ancients were well aware of the majesty of tall proportions. Accordingly, we find the openings between the columns high and narrow. Besides their other advantages, the flutings possessed that also of increasing the apparent height of the column. In order to make them prominent they were cut small and close together; in other words they were massed. The Gothic builders, likewise, appreciated the majestic appearance of high features. Indeed, their entire style is but a magnificent embodiment of their love for the majestic. As they improved in their art, higher and higher rose the vaulted aisle. The flying buttress steadied the imposing pile, and the whole stood forth so loftily that it looked like the work of fairy hands. Particularly in their interior work were they extremely successful in carrying out the genius of their architecture. The clusters of pillars which support the walls of the nave and the vaulting above, they caused to shoot upwards, at times, without interrupting their course by capitals at the various tiers of arches. The eye ran smoothly along them to the centre itself of the vault, high over the middle of the pavement. No imagination so torpid but was excited by such majesty. Those elevated vaults could be compared to the heavens only, and the beholder acknowledged without effort the fitness of the building for its sacred purpose. On the principle that pervades Gothic architecture may be constructed many features in other styles. Doorways in which the shafts or pilasters at the sides dispense with capitals, being joined without demarkation to the arches spanning the openings, have their height and majestic appearance increased. A low full centre arch sunk deeply into the wall, has, on the contrary, an air of immense massiveness. The proper employment of this arch is under monotonous masses, not too high, as in Norman architecture. Of this style, it is, evidently, the distinguishing mark. It is well adapted to the lower portion of a high and massive building also, in which position it has been successfully used; but, of course, never with the effect which it possesses in its true position, under broader and lower masses. But to express the majestic, the best arch is the Gothic. Its verticality is decided, even when the opening is not carried high. In this respect it has the advantage over the circular arch. The effect of the introduction of a keystone in a large circular arch, is bad, as the bold sweep of the curve is broken. Keystones are best employed in

narrow arches where verticality predominates. Indeed, narrow full centre arches do not possess any agreeable expression without keystones; particularly when the openings are very high. In addition to attention to arches, we must preserve the corners in a building, should the full effect of its height be desired. Horizontal divisions, if introduced, should be recessed and stopped before reaching the corners, which, in consequence, will be thrown into the form of pilasters.

The ancients never broke the course of the long horizontal mouldings and plain bands, passing from end to end of the entablature. The small repeated figures, such as modillons, dentils, and triglyphs, served to produce variety and to enhance the grandeur inspired by the long continuous features. For nothing will be grand that is not monotonous. The sky and the ocean are familiar examples. The mountains, too, with their long sweeps, are another instance of the grandeur of monotomy. Hence, in architecture, in order to aspire to real grandeur, length and surface, either straight or curved, but unbroken and continuous, must be visible. When repeated features are added, these should recur at *short* intervals that they may be analogous in effect to length. Monotony is thus rendered vigorous, which it must be to appear pleasing. Attempts made to interrupt it by drawing the eye upon something else for a while, will prove fatal to its grandeur. An inclination for novelty will often induce the designer to break his long lines with slight projections, and, sometimes, by a total change in the design, much to the advantage of the picture on the paper, but greatly to the injury of the aspect of the building. A long wall is pleasing, especially if its monotony is intensified, from its being built of stones uniform in size and color. Let a few openings be introduced here and there irregularly, and all its effect is lost. The impressiveness of the Norman tower is owing, in a great degree, to its monotony of surface. Irregular, detached, and variously shaped masses may convey to the mind the idea of picturesqueness, but they are incapable of producing in it the impressiveness of grandeur.

A structure with many vertical projections close together, besides wanting monotony of surface, presents, also, the disadvantage of not being suitable for oblique views. In order to understand the design it is necessary to stand directly in front of the building. No such defect exists in the Grecian architecture. In good examples of the Gothic it is not to be found. The vertical masses there are large and widely spaced, thus giving rise to a distinct arrangement from wherever viewed. Modern architecture, unfortunately, abounds with this fault. According to the present taste, unless a building is cut up with pilasters, projections at the ends, projections at the centre, curves here, and straight lines there, columns between the openings and porticoes never to be used, it is not considered elegant. Instead of attributing weakening effects to such irregularities, they have been attributed to openings. But apertures do not weaken by far as much as little and numerous breaks, which were the characteristics of the most debased style that ever arose. The presence of apertures, by destroying monotony leads, it is true, away from grandeur and solidity; but while disadvantageous in this respect, they compensate for the loss of effect they occasion, by giving rise, in deep walls, to powerful contrasts of light and shade. Something analogous to this may be remarked in Gothic architecture. Monotony and its grandeur, however, has not been disregarded in this style, for uniting under one grand feature the projections and voids beneath, the long masses of monotonous roof in the Gothic cathedral enable the eye to appreciate the great extent of the building. All structures which, like it, are broken in ground plan, may have such monotonous masses at their summits; while those which, resembling the Grecian temple, are compact, may place here play of light and shade, calm monotony being found on their sides. It is evident that the contrast which this practise produces, must contribute considerable to the general effect.

Smooth columns were used quite properly by the Greeks in their Doric order; the monotony of surface being in keeping with the rest of the structure. Of large diameter and comparatively short, with the view of inspiring a sentiment of immense solidity, they were employed also, with great success, by the Gothic builders in interior work. Fluted columns, like those of the Doric order, are appropriate, by reasons of the angularity obtained, to express strength. For the sake of contrast, columns are partly fluted; but wherever the fluting is placed, the lower part of the column

should project beyond the upper part. The greater amount of material should be seen beneath, whether in a column or in a building.

A building being in reality more solid at the foundations than at any other point, its base is the proper location for monotonous wall. As we rise, openings more and more numerous may be introduced and conformably to conditions of stability, the walls may decrease in thickness at the same time. The shapes of the openings, as well as the forms of the other features, may be diminished in severity as their positions are higher. The roof being the lightest part of the structure, it will bear, by virtue of this principle considerable ornamentation. Should the building be of a severe character, a strict monotony of figures, but elegant in themselves, is preferable in the roof to broken masses. This principle, it is needless to say, is well exemplified in the Grecian orders. Tile roofs, the tile being of marble, stone, or baked clay, and metallic roofs, to a certain extent, are the kind which admit of such treatment.

A part not at all inferior to monotony of construction plays monotony of color in producing grandeur. Nature, who always arrays herself in the most fitting manner, employs monotonous coloring in all her stupendous works. Only in shells, in flowers, and in small objects, do we discover the most lively beauty produced with a variety of tints. But when we turn to the mighty dome over us, shining with innumerable lights, we perceive there the same dark, solemn grandeur wherever the eye wanders over the vast scene. As the sun rises this scene changes, it is true, but is converted into another as grand, as magnificent and though less solemn, yet much more monotonous with its unvarying blue. While the change is great in appearance, in character it is slight. Still, combined in a tasteful manner a variety of colors give to a building a vivacious appearance. Such an expression is not suited to an air which, like the grand, requires repose. There is something more impressive in the silence of repose than in the tumult of action. When the sea lies spread out before us, its smooth surface slowly swelling, it strikes us with greater awe than when the storm roars and the waves are lashed into fury.

Besides great monotony and a grand repose, then is to be noticed another characteristic of Greican architecture. This is, the air of massiveness which surrounds it. Even the Corinthian order, graceful as it is, numbers among its attributes a certain tempered massiveness. The Grecian works owe this air of solidity somewhat to their squareness, but principally to their porticoes. Here rows of large columns support heavy entablatures, the solid construction of which is visible from below. No meanness meets the eye; deceit is not practised; every thing shows itself a worthy member of the whole. Indeed the portico is quite as much the glory as the distinguishing feature of the ancient orders. It is composed entirely of large stones; and its mouldings and ornaments, so well chosen and carefully placed, serve to render graceful only a real massivness. We may leave here something from the Greeks. Their work shows the necessity of abandoning the small material used to such a great extent at the present day whenever we desire to reach excellence. The Egyptians went to one extreme in the size of their stones, and we have gone as far towards the other extreme. Particular attention should be bestowed on the sizes of the stones for a contemplated structure. Because when too large they decrease the apparent magnitude of the building; when too small, their effect is lost. In aspiring to the grand it is essential to recognize the necessity for large stones and extended masses. Our skill lies in their treatment only. We may regulate their bulk, dispose them to the best advantage, but we cannot dispense with their employment. Even when these requisites are obtained, we yet need something more to make massiveness fully preceptible. The eye must observe in all classes of buildings the three dimensions. It is evident that depth will never be seen so largely as height and breadth; yet by increasing the number of points where it is visible, that is, by introducing the greatest number of openings consistent with preserving a sufficient amount of plain wall, we are enabled to obtain a strong impression of this dimension. The effect of depth is produced in a Grecian temple, by the decided projection of its details, and the distance which the main building is placed behind the columns. The thick buttresses and the deep portals of the Gothic architecture, fulfil the same purpose. When these buttresses are united to thick walls, the spectator obtains the idea of a much greater massiveness than really exists.

Ornaments, whether as projecting members, or as detached ones, contribute, in all cases, to augment depth. They may be regarded as essential features ornamented; and while this definition is in the main correct, yet, when we descend to minor decorations it is not applicable to them. The avowed object of many of these is to ornament, by varying at suitable places the *nature* of the monotony. Such features are not those which will be here considered. Larger ones, intended for utility and designed with such an object in view, will claim our attention. The most important among these are corbels and columns. Corbels and columns appearing to support something, but in reality upholding nothing, are evidently unnecessary, and should be omitted. If it is designed to introduce them, and the style of the building will allow of their use, the construction should be designed in such a manner as to make them fulfil needed functions. Columns in openings should aid in supporting the lintels and masses above them, they are ranged over one another along the stories of a structure, they have the plausibility of being necessary adjuncts, though really the projection of their entablatures may not be so great as to require support, and even these salient masses themselves may be useless. This practice, borrowed from Venetian architecture, is pursued confessedly for the sake of adornment. Not understood in its management, plain wall is supposed to be ugly, and its employment is to be avoided. But neatly constructed, particularly when of ashlar masonry, it is in itself a decoration full of chasteness of the highest order, and preferable to ornaments fastened on. Needless columns placed against buildings which they are intended to embellish, betoken a rude taste. It would seem as if transported with admiration for the beautiful features of the Grecian style, we wished to employ them in our architecture regardless of reason and suitability. Hence they appear there as appropriately as would the Grecian costume in our streets. Columns find their true use in porticoes and arcades. From time immemorial they have been thus employed. To stretch their application to the utmost, is to make them intrusive.

The slender pillars seen in doors and windows, are features different from columns in a façade. These shafts aid in supporting the mouldings above, of which they are indeed a continuation. It is not difficult, however, to conceive columns blending into mouldings at these points,

All mouldings, and, generally, all ornaments having beauty for their attribute, should be curved in outline and irregularly curved instead of regularly curved. In other words, the curves should be arcs of ellipses and not arcs of circles. The principle of contrast in its fullest application, should govern the design of a combination of mouldings. No two mouldings, or plain bands of equal height should be visible in the same portion of the building; nor should a moulding and a plain band of the same breadth be united. As a usual rule, two mouldings ought not to succeed one another without the interposition of a plain band. The Grecian mouldings being more angular than the Roman, are more appropriate than the latter for expressing strength. The Roman mouldings are better adapted to express elegance, as they exhibit much more gradation and are softer than the Grecian. Sharp changes from light to shade, introduced both by the Greek and Gothic architects, were not appreciated by the lovers of magnificence on the banks of the Tiber. It is in combinations of mouldings designed upon the principle of contrast, where acute angles find their common use, which is to give intensity to the play of light and shade. Plain bands, in consequence, are not numerous; but their complete prohibition is not allowable.

Mouldings are employed to separate features and to indicate change of form in the features themselves. As a protection to joints beneath, they are extremely valuable. The play of light and shade which they present is an agreeable property; so much so, that it may be compared to the melody of music. In order to make such play distinct, it is necessary to have a light colored and fine-grained material. Hence the superiority of marble over all the other varieties of stone. Darker stones, as may be imagined, require more light in proportion to the obscurity of their color, to produce a play of light and shade equally strong. In this respect the ancients had a great advantage over the Gothic builders; both erecting their buildings in open sites made the difference more marked.

Interior mouldings, to have their greatest effect, must receive a sufficiently strong light to bring out the shades, shadows and brilliant lines in a preceptible manner. Where this amount of light cannot be ob-

tained, no great effort should be made to attempt such decoration.

In studying the orders of the ancients, there is to be remarked not only the prominence of their ornament, but also the system which they followed in its distribution. They placed in it masses, which they separated by other masses of plain work. Indeed, plainness and ornamentation succeed each other regularly all the way up the structure. Ornaments are condensed at the bases and capitals of the columns, and the shafts remain plain. In the entablature, the architrave is divided from the frieze by a prominent moulding; and the frieze is left smooth to contrast with the mass of ornament in the cornice. Though decoration was massed, yet it was another principle of Grecian architecture never to confuse the eye by too much. This principle also the Romans do not seem to have understood. In many of their designs we are bewildered with the amount of gorgeous work covering every part of them. The eye cannot follow such extended successions of different figures, however beautiful in themselves, for it needs plain wall upon which to rest. Generally, excessive ornamentation may be regarded as an indication of decay of taste, in all the arts and in none of them more so than in the building art. Instead of ornaments being borrowed from various styles when needed, they should rise from themselves in every piece of work, springing naturally from the treatment of the subject, after it has been planned to fulfil its purpose. An architect of the present day when designing, is often apt to consider how a certain ornament would look at a certain point, and, if he is favorably impressed with its effect, he will make room for its introduction. A large room may be disfigured, a wing, an entire story may suffer, still he persists in its use, as if buildings were built for their decorations. Most commonly, again, ornament is located with the view to destroy plain wall. This is improper; indeed it is vulgar. Like a person of bad taste, the building will be decked out with too much finery.

On farther study we notice still another principle of Grecian ornamentation. All mouldings in the entablature, and in the capitals of the columns lean towards the front. This is a very natural disposition. For, as the spectator looks up to them, they display themselves to the best advantage to him. They raise in this manner a certain feeling of sympathy between him and the building. The Grecian temple, grand though it be, possesses in an eminent degree this peculiarity; this heightening of its attractive nature; this banishing of every thing repellent. A similar principle to the foregoing governs the disposition of the mouldings in the lower parts of the building. Here all are inclined to the horizon, and, therefore, placed conveniently for our inspection. It is upon this principle that the bases of columns are more pleasing when their spread is decided, than when it is slight. Besides, an air of stability is given to structures and their features, by so arranging the projections at their feet.

Arches are features admitting of much more decoration with mouldings than any other parts of a structure. They have not been always adorned in this manner; but when embellishment has been attempted otherwise, failure has occurred oftener than success. The full centre arch, as used in the early Italian churches, at the sides of the aisles, does not possess the striking appearance of the Gothic arch. This is owing, not to want of massiveness, but to an extraordinary amount of ornament induced through false taste. As an exception, however, the magnificent full centre arch at the altar, extending over the whole width of the nave, has a boldness not found in the pointed arch. Wherever the quantity of ornament at the sides of the aisle has been diminished, the improvement is very perceptible, and the beauties of the circular arch become then prominent. San Marco, Venice, is a good example of the characteristics of this arch. There, massiveness, and no mean height above the floor, add grandeur to its bold sweep across the spacious aisles. The habit so persistently pursued by many ancient architects, and still followed by many modern ones, of ornamenting the soffit and heads of the arch with sunk panels decorated with mouldings, and sometimes with rich carvings, rob it in wide spans of its true beauty. In place of this treatment, it is preferable that the ringstones be finished on the sides with an architrave, as was in part the custom of the Romans, or the soffit be flared and filled with a mass of uninterrupted mouldings, like in the Gothic arch. Again: too much plain wall over arches seems to overload them. Such practice is, in reality, placing the most solid portions of the construction

at the top. This also is a fault found in the Italian churches, but one which the Gothic builders with their arch very seldom committed.

Columns may support arches where there is a vertical pressure only; for instance, in a vaulted interior, or in a colonnade. Where arches transmit an inclined thrust, solid masses are the proper supports. These are often supposed to be ugly, and several columns are grouped together instead; thus offending against the principle which teaches that fitness for a purpose is the first recommendation for use, and that skill in art consists in giving a suitable expression.

Though Italian architecture in general exhibits a variety of styles joined together without regard to gradation of form, severe forms being often placed above the most light and graceful ones, yet it has depth, masses of ornament, plain wall, and, particularly, handsome arcades. Arcades are beautiful features, and deserve preservation in our modern practice. In Gothic art they may be seen sometimes on the exterior, sometimes in the interior, appearing usually exquisitely worked, though now and then their style is severe. Arcades, and likewise porticoes, unless they are to be of use, should never be built. Many structures have costly porticoes, which on no occasion fulfil their functions, and are intended solely as huge ornaments. Reason revolts against the employment of these useless adjuncts, and dictates, instead, that no buildings save those in which large crowds assemble should have great porticoes. City structures are here alluded to; in the country porticoes have a larger field of application. Arcades may be introduced at every alternate story, or confined to a single one in the upper part of the edifice. When on the ground floor, they appear best projecting from the face of the wall. For recesses, they give an air of insecurity to the whole mass above, which seems upheld by feeble, detached supports. The great depth, however, produced by an arcade so situated, is very effective, and compensates somewhat for this disadvantage. When half recessed and half projecting, an arcade on the ground floor assumes a character and an effect derived equally from one entirely recessed and one entirely projecting. No disagreeable impression is received in this case, as the eye cannot judge very well as to how much is recessed; indeed, it does not dwell here at all upon this point. Nothing is more disgusting than the inaccessible shams often stuck on a façade, and called arcades, though their obvious purpose is ornamentation. Real arcades are useful recesses, revealing the massive walls into which they are generally sunk.

Next in importance to arches, and often connected with them, are pilasters. They were correctly employed in the early churches of Italy. We see them there formed by making panels in the solid work, leaving always a portion beneath untouched to serve as a general base. In most instances they were placed above the eye, in the upper portion of the building, where less solidity was required, and occupying at times more, at times less than one-half the height of the entire structure. Pilasters, and shafts as well, when placed over one another in tiers, should have no bases, but should pass through capitals not very prominent. Properly grouped in a vaulted interior, pilasters give, by their angularity, an appearance of immense strength to the construction. This style may be seen exemplified in a few European cathedrals, built before the Gothic had become the prevailing style for church architecture. Sometimes the interior was made still more severe by the almost complete avoidance of mouldings, so that the angles in the vaulting were left without any ornament, and showed clearly and sharply. Pilasters may be observed grouped like Gothic shafts on the exterior of modern buildings. Such grouping of them is in bad taste, for they are features too severe to admit of graceful combination of round and slender shafts. They, however, may find considerable use suitable to their character, in strengthening the corners of edifices, the junctions of their walls, the sides of openings, and the walls themselves immediately under the roof-trusses.

It is a common practice when using pilasters in connection with columns, to give them the variable batter of the columns. Notwithstanding the authority which may be cited in suport of this custom, it is not correct. Pilasters are entirely different from columns. One is high and angular; the other equally lofty, but round. Pilasters are of a severe, majestic character, while columns are eminently graceful and elegant; attributes which, undoubtedly, may exist in them with more or less intensity, but never completely suppressed. Therefore, the gently curving batter of the col-

umn is not admissible in the pilaster. If a diminution in the latter is desirable, then it should be in a straight line.

We have still another application of the pilaster. It is seen in Moorish art. There semicircular properties are divided into pilasters, and these are connected at their upper ends with arches, which often intersect one another, sweeping alternately from pilaster to pilaster; thus forming a very appropriate decoration, not only for such features, but also for complete circular towers of elegant proportions.

The site of a building may be considered as influencing to a certain extent its ornament. Both the Greeks and the Romans appreciated the noble effect of a site on an eminence. For the building shares the grandeur of surrounding nature, and at all points of view forms the central figure in the scenery. It has, besides, a commanding appearance. These characteristics demand consideration in making the design. More attention is to be bestowed on the proportions of masses of light and shade, and of large features than on small ornaments, which evidently will not be prominent. Still the mouldings should be larger than if the buildings were subject to closer scrutiny. But the beauty of the structure depends more on its form than on its adornments. When commanding sites do not exist or cannot conveniently be established, free and open sites are next in preference. All efforts to aspire either to the great or to the beautiful in architecture will be futile, when, as in the streets of a city, the designer is limited to one, and at most, two façades. A building should stand a unit in a space sufficiently ample to furnish points of view from where good perspectives may be obtained. Though this subject should involve the purchase of adjoining properties, yet there need be no hesitation in pursuing this course with public buildings of importance. When circumstances will permit, an opposite course may be followed, and the size of the intended building may be contracted.

Structures extremely ornate, in particular, should stand in open situations in order that the eye may take a position far enough away from them to take in the whole at once, and comprehend the design. For the multitude of objects seen at close inspection divert the attention from the mass to its features, from the features to their details. Hence we may perceive why grand effects are best produced with simple masses. Simple plans also are necessary for grandeur. Complicated ones, besides being bewildering in their effects, exhibit a *few* only of each kind of feature adorning the structure, while the total number visible is considerable. On this point Grecian architecture has an advantage over much of the Gothic. Whatever be the variety of features introduced in a design, they should be gradated in prominence. This is mainly effected by placing them on different planes. Often buildings standing in open sites, and otherwise well designed, fail in this respect, and confuse the eye. In each portion of a building, some one feature from among those used should occupy the first rank, and the remainder should be subordinate to it in a strongly marked manner. Many features, therefore, will not be admissible. Indeed a few well designed and well placed are all that good taste has ever employed.

Elevated objects, such as domes, with no background but the sky, appear smaller than when they are viewed against a mass of clouds. Similarly, a large edifice standing alone seems smaller than when surrounded by other buildings inferior to itself. The Pyramids furnish an illustration of this fact. A compensation for this loss of size, however, is found in the grandeur acquired. Such being the attribute of a great building so situated, we should choose those ornaments which will be most in harmony with its character. Regard must be had to the following general principle: That it is impossible to combine all the beauties in a single edifice, that a choice must be made of those suitable to its site, and to its character, while the rest must be omitted entirely. This is Nature's method of proceeding. Hence have arisen the various expressions which are displayed in her works.

In preparing a design, proportion must first be given to the outlines of the parts, both great and small, before ornamenting is undertaken. Apparently the simplest, the proportioning of the work is in reality its most difficult portion, and the greatest art is here required. Convenience, proper economy, and finally, a suitable appearance, must be all consulted. Time and labor in no small amounts must be often expended to succeed in realizing these various objects. After everything has been determined to fulfil the first two requirements, convenience and economy, then attention may be given to appearance. The breadths

of horizontal features are to be regulated partly by their lengths, partly by the altitudes of their situations. The higher a moulding, the larger must be its size, and the more sharp its curvature, to be as distinct as those placed at the base of the building. Obscurity of situation, and color of stone, enter also into consideration. A horizontal feature which may show very plainly on a short façade, for want of sufficient breadth, may become indistinct at the farther end of a long one. All proportions on a design should be corrected either by perspective drawings, or better, by large models where light and color may unite their influences. In these models the real prominence, and the relative sizes of all features are properly perceived. It will be found that all horizontal projecting members, such as cornices, will appear narrower on paper than in reality, and all vertical members, such as openings, will, similarly, seem higher in design than in the building.

When proportioning openings we may give them any of the following expressions, choosing according to the character of the structure: They can be high and majestic, or they can be square and massive. A mean between these two is not particularly expressive; though sometimes it may be the form proper to employ. For buildings of a single story any one of these proportions may be used, provided, always, it is in harmony with the rest of the design. In constructions of two or more stories, square openings should be below tall ones, and above the latter may be those of a less decided character. Uniting the windows of two stories into single large ones, is an expedient quite common to produce high openings. The practice is hardly allowable; for it attempts to deceive by making two features *look* like one.

The ancients made large single apertures twice their breadth in height. But when several openings occur side by side, this proportion must be exceeded. In three windows placed together, each must be about three times its breadth in height, in order to produce a striking impression. This proportion should be increased still farther as the number of openings augments.

When many windows exist, as along the stories of a façade, they may be joined horizontally into groups of several, and these groups treated as just noticed. The joining of several windows into one large one, contributes towards magnifying the size of the building, and giving it a character for grandeur, by producing large masses of shade. To heighten the effect of these dark masses, they should contrast with as large masses of light, or plain wall, and, besides, the openings should be deep. At the same time, it is to be borne in mind, that the expression of a front may be destroyed by spacing the windows too wide apart. The width of plain wall between windows should not much exceed the width of the windows themselves, measured from out to out of the projections at the top. Otherwise the openings will be scattered instead of massed. This is a defect not so apparent on a wide front which contains a number of openings, as in one where there are only a few. Care must be taken, also, not to run into the opposite extreme, and place them very close together; giving to the building, in this way, the appearance of only rows of windows piled over one another. In buildings requiring the greatest quantity of light procurable, the openings must be close to each other, and as shallow as stability will permit. Structures of this description, however, are devoted to trade and manufactures, and should be designed with no other pretensions save those of economy and convenience. To endeavor to decorate them, while their construction does not admit of decoration, is bad taste. When neatly, solidly built, and with due regard to the foregoing principles, their architecture is complete. To ornament all buildings, whatever their character, diminishes the power of ornament. We become satiated with the sight of it, and when viewed elegantly disposed, it does not impress us with the force it should, though we may not be insensible to its charms. It is not natural for everything to sparkle. The birds are not all of brilliant plumage; nor the animals of equal nobility in aspect.

In order to produce effective means of shade, windows should be large when occupying prominent positions. Neither an expression of grandeur, nor one of beauty, can be given to a façade dotted over, like a die, with little dark spots. Unlike horizontal repetition, upward repetition is not agreeable, and windows placed above one another should not be exactly of the same height. A great difference in height, also, is not to be introduced, unless it is desired to convey

the impression of the upper floors being inferior to the others.

It is a principle of architecture, one conducive to stability and indicative of order, that voids should be over voids, and projections over projections.

Somewhat analogous to this principle, is that which demands symmetry in plan and elevation in all great buildings. That symmetry is pleasing nobody doubts, but that it is one of the highest beauties few admit. Nature has employed it, however, in forming her most beautiful kingdom. Indeed, the animal kingdom might be distinguished from the others by the perfect symmetry only of its subjects. In the kingdom below, in the vegetable, there is not found symmetry in large objects, but regularity instead; while in the mineral kingdom even regularity has disappeared. Therefore, unless circumstances oblige a structure to be designed on an irregular plan, efforts should be made to procure symmetry. Picturesqueness has charms, but undoubtedly it owes them in great part to its novelty. The best specimens of the picturesque show the masses united as themselves symmetrical; care is taken that they shall be so, and their union is marked in a strong and distinct manner. Many designers, not perceiving this fact, have thought that picturesqueness meant the combination of all kinds of irregularity. Hence the variously shaped openings, and the concealed entrances, and the lopsided towers, and the other absurdities which meet our eyes rather too frequently, it is to be deplored.

Next in importance to the windows, is the base of a building. By the base of a building is to be understood that portion of the foundation walls carried above the ground level, and upon which the building proper rests. It is generally a little larger in plan than the structure, and it may be built either in offsets or with a batter, and quite fitly of rough-faced masonry. With the exception of the angular projections on the faces of the stones, no other indication of irregularity should be visible. The stones should be well proportioned with respect to the size of the structure, they should be chamfered, and they give a finer appearance to the courses when of a uniform depth. The base of a building corresponds to the foot of a column; but, like the foot of the Doric column, it may be omitted. Bases are peculiarly appropriate to buildings in which horizontality or strength predominates. Structures where verticality or majesty is visible may well dispense with them as unnecessary features. This principle was observed to a certain extent by the Gothic builders, who usually made their bases low; and if, in some prominent instances, they placed their cathedrals on bases considerably elevated, their example is not to be followed, particularly in that part where they cut through them with their portals. Unless a base assumes the character of a lower story, it should have as few openings in it as possible. They may be arranged sometimes so as to be invisible in projection.

Though a base is a distinctive feature of a structure, yet, as already noticed, it does not form a necessary one. Nature presents examples in trees and in mountains of bodies without clearly marked bases, and she also presents instances of the contrary in animals. But we distinguish this difference between the two cases: in the former case the mass diminishes as it rises, while in the latter case it increases. Buildings heavily finished at top, and with bold projecting masses at many points, should, therefore, have bases. Those buildings which recede horizontally as they rise do not need them. Small features may have bases or not, according to the taste of the designer. Members like columns and balusters, which tend to uphold something, should spread out at their tops, in order to give a firm seat to the mass supported. It sometimes happens, as in slender shafts, that both bases and capitals are necessary for strength and stability.

As to proportioning the stories of a structure, this is done upon the principle previously noticed in connection with the proportioning of windows. They should diminish gradually with their altitude. Besides, elevation is not exaggerated by division into equal parts, but rather into unequal ones well gradated. Such a division of the stories of a building, or of the similar parts of any feature, adds apparent height by increasing the effect of the perspective. The gradation should be according to a geometrical series. An arithmetical series does not introduce sufficient contrast, and is, therefore, not productive of much beauty. When several bands, plain or ornamented, are placed successively above one another, but in different planes, they should be gradated in breadth according to

an increasing geometrical progression, if occurring at the top of the building, and in a diminishing geometrical progression, if situated at its foot.

We pass now to a principle of architecture often violated. This is unity of design. The observance of this principle requires that either horizontality or verticality shall prevail everywhere in a design. It demands, also, that if arches are used to span the larger openings, the lintel shall be completely excluded; and the reverse, that if the principal openings are rectangular, all the remaining ones shall have this shape. Should some windows be in pair, no single window should be introduced on the same level, and if possible, not used at all. Again, several forms of roof are prohibited on the same building. The architraves of all openings should be similar. Likewise, all projections should be either supported or unsupported. High towers require high coverings to produce harmony between the two parts; though to low towers abrupt terminations may be given. Italian belfries offend against this requirement, and, on looking at them, we are sensible of something ungraceful about their summits. Horizontal divisions on a tower may destroy to a certain extent, its verticality, so that, in this case, flat roofs may not seem very inappropriate. The spire, so extensively employed by the Gothic architects, is, undoubtedly, the most elegant method of terminating a tower.

A design having projecting masses either at the centre, or at the ends of its façade, requires particular attention to maintain unity. The belting at the base, between the stories and at the roof, should run all around the building. Where verticality is intensified, these bands may have their courses interrupted. The windows in the projections should be the same as in the other parts of the structure; when this cannot be the case, they should have a similar shape, and a height equal to the others.

A building designed with a regard for unity, and in which breadth is expressed in all its parts and features, is indicative of great strength; while one in which the masses are higher than broader, being so proportioned by vertical divisions, conveys to the mind an idea of majesty. The majestic expression seems the better one for structures which, like the Gothic, have a very broken ground-plan. Long buildings in which verticality is introduced admit, also, of the effect of multiplicity in a great degree. Bristling with pinnacles and buttresses, and windows, Gothic architecture is peculiarly multiplex in character. Indeed, though multiplied objects may be introduced in a greater or a smaller number in all styles, yet never as effectively as in the majestic style. Multiplicity in the form of alternate repetition, is a characteristic of Grecian architecture. In their courses of masonry, and in their ornament, the Greeks were extremely fond of using it; but, still, confining it always to details of minor importance. It is, no doubt, a happy arrangement, and may well be practiced in our architecture when the elegant, more than the grand, is desired. It finds its application wherever there is a series of features equal in form and purpose. The expression of strength can be given to buildings, the ground-plans of which, though somewhat broken, yet are perfectly simple, regular, and composed of large masses. A structure of a compact form is, however, the best suited for this expression. But, in all cases, before adopting it, the designer should know first if circumstances will permit the height of the building being limited accordingly. Of course, the extent of the structure influences such a consideration, though in an open site, out of a city, this is a secondary matter.

While it is desirable to employ either horizontality or verticality throughout, still there is nothing to prevent us from following the practice of the Greeks, and unite one with the other in the same building. Both should not aspire to an equal prominence; but one must be subordinate to the other, and massed along a suitable part of the structure. In Grecian temples the columns with their openings and flutings are all in one place, and visible at one view. In Italian palace architecture we have another instance of the correct combination of horizontality and verticality. The lower story serves as a base to the upper ones, and is horizontal in its character; while the upper ones are thrown, by means of high and bold pilasters, into a single feature, in which verticality predominates. Buildings of several stories, similarly, should exhibit horizontality beneath verticality, the former denoting much more massiveness than the latter. And when this practice is pursued care must be taken not to destroy the horizontality with vertical projections, nor the verticality with horizontal projec-

tions. This is a great fault of modern art. More than one beauty in one place is an idea fatal to all true decoration.

Among the many features which claim attention with respect to unity, the oblique line, perhaps, is one of the most important. Its inclination is regulated solely with the view to increase the effect of either the height or the breadth of the member to which it serves as a limit. The Greeks could not have been ignorant of the fact that a triangular truss is stronger the greater its rise; particularly, since they made it support, in their roofs, heavy coverings of marble slabs. Yet they did not avail themselves of such knowledge on account of the more pressing necessity which existed to intensify breadth in the pediment, in order that the structure might preserve its unity of expression. With an equal regard for the principle of unity we behold the Gothic builders raising the pitch of all their coverings. Throughout their entire style, in the details as well as in the masses, nowhere does an oblique line occur which is not inclined at a considerable angle to the horizontal. Nothing, indeed, can give so much character to a building as unity. Structures of several stories are greatly improved in expression, when to a variety in the size of similar features, and even in their form we perceive united a resemblance which reminds us that such members are in harmony with one another, and are all parts of the same whole.

An entrance should be in proportion to the size of the building. A large edifice requires a correspondingly noble entrance. When the second floor is the most important one, a flight of deep and wide steps should lead to it. Modern steps are too shallow to be compatible with many buildings to which they are attached. The steps used by the Greeks were in some cases slightly too deep; but the error was in a good direction. Unless entrances are in the form of porticoes, they ought to project very little beyond the face of the building, when imbedded in massive walls which are to be displayed. In the finer efforts of the Gothic artists this principle is exemplified. At the same time being desirous of heightening the majesty of the portal by enhancing its size, they carried up the projecting portion high above the opening.

In adorning a building, the mouldings should be larger, more angular, and joined to deeper and more abrupt recesses on the outside than on the inside, where they are smaller and exhibit a greater amount of gradation. For distant views, as has been mentioned, large and well contrasted ornaments are necessary, in order to make them seen as far as possible. Though mouldings are not rigorously prohibited at the base of a building, yet, like in the Doric temple, we should limit them greatly in size and number. This is not often the case, however, in Gothic architecture. The arrangement of vertical mouldings, and the grouping of pillars around central piers supporting vaulting, should be governed by the principle of contrast. The repetition of the same moulding in the deep recesses of the Gothic arch, is to be noticed, with its tendency to exaggerate the thickness of the wall. In the better examples of the Gothic style, the ornamentation, including mouldings, is confined almost exclusively to the interior; while on the exterior a great amount of large angular masses are to be seen. The propriety of this practice becomes evident when it is considered that ornaments are minor features, not suitable for distant view, and, therefore, never as important as the disposition of the light and shade. Indeed, when angularity is required principally on the outside, and curvation can be introduced effectively inside, then both will be the most advantageously placed. The decline of Gothic art was simultaneous with the disappearance of this principle. In all its great works, the student observes with pleasure how ornament was sacrificed to real grandeur, how vigorously horizontality was made subordinate to verticality. Where a modern designer would carry his mouldings around, as at buttresses, the old cathedral builders stopped them abruptly. In ancient art we notice the contrary, how unbroken are the long horizontal lines. What grace would a Grecian temple have, designed according to the taste of to-day? It is often imagined that simple work, however expressive, requires no art, and that where the eye is confused with a multitude of forms there must be much skill. This is, unfortunately, an opinion too prevalent. Things apparently the simplest, which seem so easy of execution that the novice flies with eagerness to imitate them, but, as in catching the will-o'-the-wisp, to have only a weary chase, are the work of real genius in all branches of art.

Superior to all ornamentation by mould-

ings, is that with statues. However few the carvings and mouldings about a building, if rich in statues, it has a beauty noble and attractive. Under the genial sky of Greece, statues may be exposed to the weather without injury, but in a humid northern climate a different practice must be followed; they require to be placed in niches, or under protection, and a lesson may be learned on this point from the Gothic architects.

Having discussed the more important esthetic principles of architecture, we shall now pass to consider their application. For this purpose buildings may be divided into several varieties, varying in the severity of their treatment. It is plain that verticality and horizontality are independent of such a classification, and thus there is obtained the scope necessary for classifying under a few heads the many styles which abound in architecture. Further, to each of these styles, independently of the others, the same classification may be applied; indeed it marks the changes they have undergone during their existence. In the Gothic and Grecian styles no difficulty impedes its application. This premised, we shall commence with the expression requiring the most severity in its treatment, which is that of grandeur.

In order that a building may appear grand, it should be large; contrast must be introduced to a great extent, and gradation visible in the small features only. The large masses, therefore, ought to be angular, while the openings must be covered by lintels. Prominent ornaments should be used sparingly. A few large mouldings, and as many small ones, may be introduced, but no more. The cornice alone, if one is needed, should exhibit a great contrary flexure. The rest of the mouldings should approximate nearer to the Grecian than the Roman type. It is necessary to imitate nature, and present, either on the walls or on the roof, strict monotony in extended masses of plain work; taking care, at the same time, to have properly disposed masses of shade, of lines, of ornament. Large stones only, well proportioned, should be visible. Depth in openings is absolutely needed, and its effect must not be enfeebled by any attempt to diminish the intensity of the shade. Hence the sharp edges of the openings should be preserved. When it is feared that the openings are not sufficiently deep to produce the intensity of shade required, then bold projections may be introduced. These are readily obtained in a structure characterized by verticality. In one where horizontality prevails, the method of producing them is to give the cornice a decided boldness, support it with no corbelling, and treat in the same manner the upper projections of the openings. Instead of making the outer surfaces of these projections perpendicular, to increase their bold effect they may have, with their mouldings, an inclination towards the front. This practice has been previously noticed in connection with the disposition of mouldings, and other effects besides have been attributed to it. Architraves, if used at all, should be plain. Pilasters introduced at the corners of the edifice and at the junctions of walls, where horizontality prevails, should be designed quite broad. Balusters, likewise, should have their breadth intensified.

A large building, to be surrounded with an air of extreme severity, and not to show any great attempt at refinement, must be massive, contain large extents of plain wall, and, to enhance its massiveness, must have its openings narrow, not high, and deeply recessed. When curvature is introduced either in the masses or in the details, it tends to soften somewhat the severity; though combined with breadth, as in Norman architecture, experience has shown that it is adapted to the severe. Symmetry such a building needs; as well as order in the arrangement of the openings. No moulded cornice, and no ornaments without use, should be employed. In case columns are used, they ought to be heavier and plainer than in the previous style, resembling more piers than columns. The severe, and not very inviting aspect of this style, and also its great massiveness, causes it to be well suited for the architecture of punitive institutions.

On a similar principle elegance should be the characteristic of all places where the mind is to be cultivated. But elegance in a building is, of all expressions, the most difficult to attain. The projections, though decided, should not be so prominent as in the grand style, and when as large, should be supported with corbelling. The openings may be either arched or not, tall and ornamented. Gradations ought to be frequent, and reflected curvature may be introduced in the corbelling and mouldings. Masses of plain wall and of shade are still

necessary, but not as extended as for expressing the grand, which fact will give, consequently, more room for ornament than in that style. Still, ornament should be introduced neither sparingly nor in profusion; it should be employed in judicious quantities, and wherever placed, as usual, it ought to be massed. Elegance has been obtained, like in the Ionic order, with little ornament. When designing this expression, it is preferable to feel as if sufficient ornament has not been used, rather than to imagine that it can bear all which has been put on. Smooth, finely fluted, or reeded columns are very appropriate here.

The difference between the elegant and the ornate lies not only in the amount of decoration, but also in its character. That of the ornate style should contain more curves of double curvature, while carving may be introduced at various points. All openings permit of being surrounded with elaborate architraves. Gradation in their forms may be practiced, like in the elegant style; but, when desired, the apertures may all be light and semicircular. The principle of contrast of light and shade, that is, of depth in openings and recesses, should be still kept in view, if the ornament is to possess distinctness and the building vivacity. To aid in promoting these effects, plain wall should be preserved in sufficient quantities. When a cornice exists it may be richly ornamented, but never so much as to destroy alternation between decorated and plain surfaces.

In villa architecture, where a polite air is to be given to the building, order, neatness, and small ornaments only, should be introduced. The most important considerations are, proportion, unity, play of light and shade. The height of the stories, that of the roof and the sizes of the openings, these influence greatly the appearance of the building. Surrounded by the gay aspect of nature, villa architecture is the proper field for the picturesque. The undulating ground, checkered into squares colored in various shades of green, and gradually rising in the distance till lost in a long sweep of blue hills, the cattle scattered over the meadows, the trees grouped around the dwellings, and dotting, some here, some there, the entire prospect, form a series of circumstances propitious to the employment of this style. The picturesque results, therefore, more from a collection of many objects than from any single one. It was so understood by the Greeks, who alive to its beauties, arranged their public buildings around squares adorned with trees and statues. These structures differed from one another in size, object, and situation, but were always symmetrical. Here was to be seen one nestling in a grove, there another rising above them all and presenting its pure white in striking contrast with the green foliage around, while still in a different direction several close together, casting shadows from one to the other, charmed the eye with their negligent gracefulness. Long porticoes, also, some devoted to pleasure, some used as markets, gleamed through the trees. All such combinations of art and nature produce those accidental lights and shades characteristic of the picturesque. When the effect of a group of buildings is to be *imitated* in a single one, in order that the imitation may be correct, the various portions of it, as previously stated, should be symmetrical. Whatever the amount and vivacity of the play of light and shade thus obtained in one building, its effect is insipid compared to that of the true picturesque. This requires space to display itself; nature and art exert their powers to create it; a graceful, negligent irregularity, not in its objects, but in their arrangement characterizes it. No hope exists for the picturesque in cities solid with brick and stone.

It will be observed that general principles only have been given respecting the attainment of the various expressions pertaining to buildings. No complete set of rules can be laid down, to arrive in each case at the desired end, for each case demands particular study. Sufficient, however, has been said to conduct this study along the proper path, and even to advance it considerably in this direction.

Architects have discussed for a long time the advent of a new style; a style which is to follow the Grecian and the Gothic. Many have striven for the glory of producing it, but their attempts have resulted in failures. This is what might be expected; for styles were never sought; they rose to satisfy the needs of the times; rough in appearance at first, they became afterwards polished. Without the sublime mythology of the Greeks, the world would never have had the Grecian orders; without the Christian worship, no vaulted aisles would have filled with the swelling notes of the organ; without the Moslem creed, the minaret

would never have been erected to praise the Creator, and call the earth to prayer; without Norman valor, Norman castles would never have frowned from their misty heights, and without luxurious Italy, Palladis would not have designed the architecture which has made his name immortal. It may be asked, then, have we not our needs? Our century, certainly, has not been wanting in activity; and, though boastful, has accomplished some great things. Institutions of learning, of science, and of art, halls and theatres, manufactories and warehouses, railway stations, public buildings, and private residences at all degrees of cost, open an ample field for the exercise of genius. If these constructions be designed to fulfil to the greatest advantage their utilitarian purposes, no regard, meanwhile, being had to decoration, they will then indicate of themselves, to a clear mind, their proper dress. Thus only will we arrive at styles peculiar to our civilization. It was in this way that our predecessors in art obtained their triumphs. Our needs being many, our styles will be numerous. Also, they will be flexible, and apparently variable, yet governed by underlying principles.

But we must guard against the desire to build more cheaply and easily than is warranted by experience. For art depends as much on material and workmanship, as on taste. It is quite lamentable to perceive how far a desire for economy has insinuated itself in all our work. After a structure has been planned as economically as possible, it usually enters into the head of the builder to decorate it, and give it some pretension to taste. Hence, ornaments attached with hooks; hence veneers of stone and of marble. How long can buildings preserve their appearance, built and adorned in this manner? Indeed, what length of time can they last? If executed with the view of transmitting them to posterity, as samples of our skill, what can be the judgment of posterity? The evil would not be so conspicuous, if architects and mechanics would regulate their taste and work by sounder maxims, when employed on a structure of importance. But here also false economy brings with it all manner of deception. The fine is desired, but it is only imitated. The imitation, besides, is the uglier from not being complete, and imperceptible. Sometimes it is placed solely on the front of the building, while the side and back exhibit an honest bareness, and a more ordinary material. The greater cost which is required to carry out the principles of genuine art, no doubt, may check many from attempting it; but by bestowing on essentials that which is so generally spent on foolish ornament, a great amount of the additional cost disappears.

There is another course to pursue; which consists in moderating our aspirations, and contenting ourselves with humbler efforts. Workmanship and material ought to be of equal endurance, so that both may decay together, and not one outstrip the other on the march to ruin. In general, let us have ashlar masonry with real headers and stretchers, like in olden times; with beds and joints dressed deep into the wall, and as carefully for stability as the face for beauty; let the backing be as attentively built as the visible part of the work; let vaulting and massive walls contribute towards rendering our edifices grand and lasting: let the art of stone-cutting be developed among us in all its beautiful branches; let a severe, classic taste preside over our designs; let a building show on all sides the same material, the same attention to please; let a private dwelling look like one, and not aspire to the highest flight of the art—a Grecian temple; let Gothic be Gothic, and not imitated from imitated Gothic; and finally, let us insist upon truth in art as in morals, remembering that a good effort, though of an humble kind, has character and a rank in the scale of art, whereas one which intends to deceive, is passed by unrecognized.

The principles detailed in this paper, are those to which the author has been led in his search after the true. The Grecian and the Gothic, as styles universally admired, have been his guides; while by their light he has seen in others much to laud and much to condemn.

PHILADELPHIA, *Aug.*, 1874.

THE manufacture of a rifled gun weighing 81 tons, was recently begun at the Woolwich Arsenal, England. It will throw a shot of about 1,600 pounds weight, and is intended for the iron-clad Inflexible, which will carry four guns of this kind in its turret. They will be the largest pieces of ordnance in the world.

HEAT AND WATER.

From "The Engineer."

The relations of heat to matter have been carefully investigated by many able men, and from the phenomena exhibited by matter in various forms when heated it has been found possible to deduce certain laws of the last importance in science. But while we admit so much, we are also constrained to confess certain phenomena connected with the relations of heat and matter require an explanation which they have not as yet received, and the reason for this is twofold. In the first place, men competent to the task have not found time to investigate almost isolated phenomena, which from the rarity of their occurrence do not force themselves on our observation; and in the second, from the fact that heat is but a form of energy and not an absolute self-existing entity, complications are introduced into the phenomena to which we refer which permit plausible but unsatisfactory explanations to be assigned for events seemingly so rare that many persons are disposed to doubt that they can occur at all. The relations of heat with that form of matter which we call water, are very peculiar, and it is not perhaps too much to say that they are very far from being fully comprehended; and yet as the engineer has a great deal to do with heat and water in combination, it is extremely desirable that the behavior of the latter under all possible circumstances when submitted to the influence of the former, should be perfectly understood. It would be impossible with the limits at our disposal here to go deeply into this subject. There are, however, one or two points connected with the subject which may be discussed with advantage in our pages. But we must caution our readers that we have no intention of doing more than calling their attention to a few facts, drawing a few deductions from those facts, and leaving to others the task of saying whether the deductions which we suggest in anything rather than a dogmatic spirit, are or are not justifiable.

No one will dispute that in all that concerns the generation of steam, engineers are deeply interested. The process constitutes in itself perhaps the most important application of natural laws to a given end, known in the arts or sciences. How much do we understand about the operation of natural laws in this particular case? Men must have something before them real, tangible, apparent to their senses, on which to hang their faith. In spite of all that has been written and said on the subject, there is a deep-rooted conviction abroad that heat or, as some people still call it, caloric, is a distinct entity. It is so easy to picture to one's self a fluid set free by burning fuel, poured through the boiler plates, and absorbed by the water. Again, water is looked upon as so much extremely fine shot into the interstices in which the caloric finds its way, and forcing them apart little by little, at last overcomes their mutual attraction, and separates them so widely that they become steam. Such a theory is readily grasped. It is, in a word, popular, and it is we know still held by thousands of fairly well-informed men. Others, although they will not put their ideas into the same shape, yet find it almost impossible to get rid of the notion that heat is a material fluid, although they admit that the results of its operation are vibration. Now we know that both theories are wrong; if anything is certain, it is that that vibration of atoms, which is, as we have said, attributed to the influence of heat, is heat itself. "Heat," says Tyndall, "is not matter, but an accident or condition of matter, namely, a motion of its ultimate particles." "The condition of heat," says Rankine, "is a condition of energy—*i. e.*, of capacity to effect changes." Rejecting, therefore, as untenable the idea that heat is a material fluid, we are bound to regard it as a condition or state of matter, and for the accepted and precise definition of this state we are indebted to Rankine and Thomson. We shall not attempt to go deeply into this definition here. It will suffice to say that the fundamental suppositions of this hypothesis are that bodies consist of atoms; that each atom consists of a nucleus surrounded by an elastic atmosphere; and that thermometric heat consists in circulating currents, eddies, or vortices, among the particles of the atomic atmospheres, giving them a tendency to recede from their nuclei and occupy a greater space. From this theorem it has become possible to lay down a definite law of the operation of heat—to determine, in a word, the dynamics of an atom; and

this, be it observed, although at the outset it is as difficult for the mind to conceive the true atom as it is to realize a true point or a true line, according to the Euclid's definition of each. Just, however, as Euclid was able to dispense with an accurate mental comprehension of a point and a line, so is it possible to dispense with the perfect perception of an atom. Instead, we may, nay we must, take something which the mind can grasp; and as the student invariably regards a point in spite of Euclid's definition as a dot, and a line as a fine pen or pencil mark, so in dealing with heat we are justified in identifying the atom with a molecule, and a body of water as so much very small shot, each surrounded by an elastic atmosphere, and these particles and attendant atmospheres continually vibrating or moving among themselves, motion never ceasing until the point of absolute zero, or of no heat manifestation, or about 461 deg. below zero Fah., has been reached —a state of matter, we may add, utterly unknown on this earth. Once we have got thus far, however, we are stopped by an impenetrable wall, beyond which we cannot go. Why the particles should possess motion—in other words, why heat should exist, or why it should be stored up in matter as it is, we can no more explain than the action of gravity. The hypothesis of heat, as we have given it, is good so far as it goes, because it is consistent with known facts. But it must be borne in mind that heat, or strictly speaking, that form of energy known as heat, may produce effects of which we know next to nothing; and that its operation on various bodies is marked by certain anomalies which are not as yet fully accounted for. And this is specially true of water. The first action of heat, for instance, is to cause expansion. The atoms of the body tend to separate and vibrate through larger arcs or ranges. But water expands as it loses heat from a temperature of 39 deg. Fah. downwards. This has been explained by the theory of crystallization. The particles apparently begin to segregate themselves, and to leave open spaces between each group. Why this should be, however, cannot be explained until we know why crystallization takes place—a profound mystery to the entire scientific world at present. The fact exists, nevertheless, and it supplies a somewhat familiar example of the truth that heat may produce, as we have said, effects of the true nature and sequence of which we are in total ignorance. It would be opposed to our experience, for example, to say that by the application of heat we could solidify mercury; but there is not any difficulty in imagining when we have the expansion of water with cold before us, that a fluid might exist which would solidify under the influence of heat. It is essential to the comprehension of the line of argument we are adopting that our readers should realize the fact that heat is but a form of motion; that motion can be changed into heat or heat into force, but that we do not know the precise conditions which determine the conversion of heat into any other given form of energy. Thus, heat, light, and electricity, mechanical work, and magnetism, are all developments of energy. But it would be erroneous to assume that we know precisely when heat will become mechanical work instead of light or electricity. We do generally, and we can predict with tolerable accuracy the conditions determining the form which energy may assume, but nothing more. In a word, we do not know all about heat and its mode of operation, its influence, and its transformations. The world has a great deal to learn on the subject, and nothing can be more fatal to the spirit of investigation than to believe that our knowledge of the laws and phenomena of heat has reached the culminating point, and that Rankine, Joule, Clausius, Thomson, and Tyndall, have told us all that can be told on the subject.

Presuming, then, that we do not yet know all that is to be learned about the relations of heat and matter, let us see whether out of this very ignorance we may not be able to draw some deduction of value. Let us, for example, apply our want of knowledge to the case presented to us by a boiler explosion. We shall be the last to dispute that nine hundred and ninety-nine boiler explosions out of a thousand occur from perfectly well-known causes; but we submit that certain events tend to show that boiler explosions may occur—but we do not say they do occur, be it remarked—from causes which are not understood and from the operation of laws not yet recognized. We have in every boiler, when under steam, an enormous quantity of energy stored up; that energy is practically in the same condition as the powder in a gun—it needs but the touch of the trigger to set it free. The millions of foot-pounds of work stored up

in a large boiler do not operate as work at all, because the motion essential to the performance of external work is not permitted to begin among the particles. The condition is precisely that of a piston of an overloaded engine—reduce the load and the piston moves, and the steam impelling it will give off hundreds of thousands of foot-pounds each minute, although before it was inoperative. Reduce the load on the water in a boiler, and the energy stored up can become motion, work will be done, and once it commences the result is seen in rent iron, shattered buildings, and torn and mangled human beings. There is not a boiler at work to-day that does not contain within its shell a force sufficient to rend it into atoms, and to create destruction around it. Is it then impossible that a condition favorable to the performance of external work may arise within a boiler? Is it certain that the stored up work cannot get permission to begin to manifest itself? Can it be proved that the only manifestation of the influence of heat on water consists in the conversion of portion after portion into steam? Such questions as these must not be dismissed flippantly. It will not do to assert that heat invariably, at all times and at all seasons, converts water into true steam, and does, and can, do nothing else with it. We have in a mass of heated water a condition of matter not remote from that condition of unstable equilibrium which obtains in explosive mixtures of gases or solids. Only a spark is required for the letting loose of the energy stored up in gunpowder or dynamite; and it may yet be found that the equivalent of a spark exists with regard to the stored up energy in water. Indeed, we know, as it is, that an equivalent does in one sense exist. The equivalent is the fracture of the envelope containing heated water under pressure. A moderately large rent in a boiler will cause a reduction of resistance sufficient to establish free motion among the atoms in repulsion, and the destruction of the boiler is complete in a moment. It is possible, indeed, to have an explosion of any violence we please—it is simply a question of opening a sufficiently large rent to set the water free to expand and do work. If the opening is great enough, the water stored within the boiler will, to all intents and purposes, explode; and this, we maintain, is one of the manifestations of heat energy on water which has not been investigated as fully as is desirable. It may be urged that water cannot explode. Any one who has been in a rolling mill working with watered rolls knows the contrary; each time a hot bar goes through, we have a volley of reports as though so many rifles had been discharged. Water quite freed from air may be heated to 312 deg. without boiling, and will then detonate like so much fulminate of mercury. It is difficult to believe that in such a case any true steam is produced; the probability which we would urge on the attention of our readers is that instead of a portion only of the atoms of water flying apart to the distance required to produce true steam, a manifestation of energy takes place simultaneously through the entire mass of water, be it a drop or a ton, and that the result is a very considerable dilation of the entire mass without the production of true steam. That such a dilation is possible has been proved by laboratory experiments, in which the whole of a small quantity of water has been caused to become invisible, although the resulting steam, if so it may be called, did not occupy more than two or three times the space originally filled by the water. If we grant this to be possible in the case of the water in a steam boiler, we admit nothing but that heat can manifest itself as a form of energy in a way not usually met with. It is no more inconsistent with reasonable presumption to suppose that the work stored up in a boiler should suddenly be displayed in the tangible form of dilating the whole mass of water, and driving its particles farther apart, than it is to suppose that the only effect of the operation of a furnace will be to produce steam. It is contrary to experience to suppose that such a dilation can take place, but only to an experience which it may be asserted is limited. It may be pointed out again, that in every case where a boiler bursts with violence the exploding power of water is clearly proved. If it is argued that water cannot explode—by explosion we mean here the disseverance of a body of water into the finest possible spray, a spray of molecules by the natural repulsion of the molecules due to heat—then must the violence of a boiler explosion from any cause, such as corrosion, or over-pressure, or shortness of water, remain utterly without explanation. But we know that the natural cohesion of the molecules is here overcome in an instant; and that water highly heated

does explode like so much gunpowder, and that to cause highly-heated water to explode, it is, for one thing, only necessary to remove the pressure suddenly. From this follows the deduction with which we must conclude this article, namely, that if it be possible for water to explode under one condition, well understood, that it is not impossible it may explode under other conditions not understood, and as a result of strictly natural laws, the operation of which has not yet been recognized.

ARCHITECTURE—ITS SCIENTIFIC AND ESTHETIC ASPECTS.*

From "The Builder."

No one who is at all deeply imbued with a feeling of devotion to his art, and who has had to carry out his views, as best he could, in the rough friction of every-day life, with its many hinderances and discouragements, will undervalue the difficulties which beset those who would speak authoritatively about architecture.

An artist in such a case would know but too well how far his own works have fallen short of his cherished ideal to be inclined to adopt that spirit of fierce denunciation which so often passes now-a-days for a knowledge of art. He would naturally be the severest critic of his own achievements, and would know that to his criticisms a *tu qouque* retort might often be expected. Nevertheless, whatever the difficulties which beset him, the lecturer must remember that in art, as in religion, the message is everything, the messenger nothing; and that in matters appertaining to architecture, more especially, difficulties only exist in order to be conquered.

I can never forget my first experience of the Royal Academy lectures on architecture by Professor Cockerell. With him devotion to his art was a passion, chastened and regulated by the refinement of a scholar, and the thoroughness of a most conscientious artist. Urging, both by precept and example, the importance and exquisite beauty of Greek architecture, he was ever ready to hold out a helping hand to the wayfarer in other paths of art, for to him every artist was a brother.

Since those bygone days there have been many changes in public taste and practice; and it can do no harm to recall to memory a time when much was enforced which is now neglected, and to caution the art student, as Professor Cockerell was fond of doing, against mere "fashion" in architecture.

It might be instructive, and certainly would be interesting, to inquire into the various "fashions" which have prevailed since the days when this warning was first addressed by the Professor to the students of the Royal Academy in Trafalgar-square. Greek art and traditions were then more fully recognized by architects, in practice, than is now the case, and the Gothic revival was in its infancy. Professor Cockerell was led by his natural taste, and also by circumstances, to enter into the spirit of the architects of ancient Greece with all the devotion of an enthusiastic nature, much as was the case with our late distinguished member, Mr. Gibson, with regard to sculpture.

The latter, as we have lately been reminded by Mr. Atkinson, would never tire of maintaining that the Greeks were always right; and his first object, when engaged in composition, was to discover how the Greeks would have dealt with a similar problem.

His architect brother artist had arrived by study and research at a very similar conclusion. Although not slavishly adhering to precedents, his works are so pervaded with the delicacy and finish of Grecian influences, that we can fancy him ever referring to these classic principles as the main test of excellence, and repeating with Gibson, "The Greeks are always right."

He neglected no opportunity of urging, by precept and example, the study of Greek art; and I venture to think that such advice, although it may not for the moment be fashionable, was never more needed than at the present time.

Professor Cockerell had, moreover, an especial claim to attention, as having contributed in no small degree to bring a knowledge of his favorite architecture before his profession and the public. By his discoveries at Ægina and Bassæ he added fresh materials for that appreciation

*Extract from a lecture at the Royal Academy, by Edward M. Barry, R. A.

of Grecian art which led thoughtful artists to consider what must have been the exquisite keenness of perception, mingled with a wondrous refinement in regard to the subtler effects of beauty, which animated those architects of old, who had so perfectly learned to work, hand and hand with the sculptor, each being necessary to the other, and each contributing, to an extent never yet surpassed, to the perfection of the work before them. The enthusiasm which the Elgin and other marbles excited among lovers of art, led naturally to a strong admiration of everything which belonged to Greek architecture, and to a general attempt to introduce its forms and decorations into the buildings of the day. In this work Professor Cockerell had no small share; and though some of his teaching may seem to have been since engulphed in those whirlpools of fashion which he deplored, it is not easy to prove that our art has passed into a more healthy condition by the adoption of different principles, or by the imitation of different models. I must therefore impress upon architectural students the necessity of studying with more care than is now too often given to them, the principles of Grecian architecture. This is, of course, a very different thing from advising a pedantic reproduction of forms, or an actual copying of examples, which no one would deprecate more strongly than myself. Too much of this has been done already, and no one can desire the repetition of a movement which encumbered our houses and public buildings with useless features, inconsistent with the wants of the nineteenth century, and the exigencies of the English climate. But, while avoiding this snare, can it be useless to draw attention to the refinements which were habitual with the Greeks, although they can scarcely be discovered by our apparently rougher perceptions, without previous study and the practice of critical observation?

The entasis of columns may be referred to as one of most prominent illustrations of my meaning. No one would now dream of designing a classical column without entasis, but this was not always the case; many modern columns have been made with straight sides, and the discovery of the refinement of the entasis was only made by careful study of the best examples.

Mr. Penrose has shown us how many similar delicacies of proportion exist in Grecian work, to reward the student who has eyes to see and taste to appreciate the hidden beauties which lie beneath the surface.

Surely there are lessons here for the art student of all times; and who can say that in these pushing, eager, restless days, there is no room for the still small voice which teaches that breadth, simplicity and refinement of proportion and ornament are the very essence of art, and that they may be seen displayed in the architecture of Greece as they have never been before or since.

While calling to mind my pleasant personal recollections of the days when Professor Cockerell enforced these principles from his chair with so much learning and earnestness, and a charm of manner peculiarly his own, these reflections have pressed upon me the conviction that whatever may be the dominant fashion of the day, an investigation of the principles of beauty in art can never be without advantage, and that in such an inquiry the triumph of Greek architecture must ever hold a prominent place.

I can also the more gratefully dwell upon Professor Cockerell's teaching from a remembrance of the catholicity of his doctrine. Striving by study and careful examination to detect those principles of beauty which must ever be the same, however differently they may be illustrated or emphasiezd in various styles, Professor Cockerell gave no encouragement to an intolerant depreciation of forms which were not those to which he gave his special allegiance. No one could express more heartily and unreservedly his admiration of Mediæval architecture; and some of you may remember the learning and artistic sympathy which he brought to bear on Wells' cathedral and other Gothic masterpieces.

As regards this liberality and breadth of view, it cannot be out of place to point out that if, with our historical knowledge, we are ever to have great artistic achievements in the future, the artist must rise superior to those prejudices which would seek to close whole volumes of past history, and would confine him to a narrow line of study, and still narrower sympathies.

It is now seventeen years since Mr. Cockerell retired from the Professorship of architecture at the Royal Academy, a few years only before his death, in 1863, which left a gap in our profession that has never been exactly filled. It may well be said of

him, that his works live after him, and that he has left enduring claims on our respect and admiration in this place.

In entering upon the object of these lectures it must, I fear, be admitted that the prospect before the architectural student has never been more beset with perplexity than at the present moment, when so many difficult problems are daily pressed upon us for solution.

What form is our art to assume? On what styles of past days is it to be based? Or is it to be altogether new? In what way are modern scientific discoveries to be dealt with? Is an architect to be a sculptor and a painter also, before he can be termed a true artist? These are only a few of the controversies which will readily occur to your minds as now calling for consideration, while over and above them all voices are loudly heard proclaiming that our whole system of architectural practice must be revolutionized, and that success will best be achieved by deposing the architect from his post of supremacy in favor of a commune of workmen.

Many signs of the times point to a disorganization of public taste, leading to an indifference to what is good or bad in architecture; and it daily becomes more necessary to find some resting place on the true principles of art.

If we look around on the state of architecture generally among civilized nations, we must be struck by the fact, that all over the world a period has occurred when its productions have ceased to display the higher artistic qualities formerly inherent in them, as if they had been suddenly paralyzed by some fatal disease. In our own country we can trace the wonderful progress of Mediæval art, from the days of Harold to the time of the Edwards, and thence by a process of decline to its fall, in the Tudor reigns. We have since seen revivals, both of classic and Mediæval types, and of these I must hereafter speak a little in detail. It is certainly difficult to assign the reason why, up to a particular time, it appears to have been natural for men to love and achieve beauty in their works; while, in these later days, ugliness would seem to be the common heritage.

We know that, formerly, every detail of architecture was replete with interest, as if by instinct, so that the very hinges of doors were works of decorative art. This, moreover, was not done, as it might be done now, in exceptional cases, but it was the rule. The men who carried out these works were evidently penetrated with the spirit of their art; and it was as natural to them to work gracefully as it is to the modern workman to create useful ugliness. This difference of spirit dates chiefly from the discovery of printing, and the Reformation, which encouraged freedom of thought, and opened to the intellect of mankind paths till then closed or little frequented.

We cannot suppose that the sum total of human intelligence decreases as years roll on and the world grows older; but may it not be that we shall find the explanation of the apparent decline of the artistic faculties in the diversion of force, occasioned by the devotion of the intellect to other lines of thought and achievement? In past times the want of facile means of communication kept the bodies of men rooted to the spot where they were born, and the absence of intellectual freedom closed to their minds those spheres of usefulness which are now open to all.

Abbeys and cloisters contained recluses, who, in separating themselves from the world, were glad to devote themselves to those artistic pursuits, such as architecture, painting, sculpture, music, illumination, embroidery, and the like, which would add to the splendor of the church and its services, and would be free from any suspicion of heretical free-thinking.

The pursuit of learning has had an opposite effect. It has prevented the intelligence of the world from being concentrated on any one subject, or group of subjects, and it has caused the great mass of the people to care more for philosophy and science than for art.

We are surrounded in this place by the buildings of learned societies, and there are many others scattered about London and the country, while the progress of science adds daily to their numbers. I was astonished to hear lately that for telegraphic engineering, a profession almost of yesterday, there is now an institution numbering upwards of five hundred members.

Before this scientific activity became possible, we may assume that a large portion of the intellectual and constructive powers of mankind which are now given to it was likely to be devoted to some of the various branches of art, which was, in fact, the common language of the educated classes.

We may as well expect to turn back rivers to their sources as to reverse the great tide of modern thought; and all experience of its tendency shows that it flows in the direction of the division of labor. The stream of knowledge is now so great that no man can venture to think he has mastered it all; and even the greatest minds must be contented to follow thoroughly some rivulet of truth, while accepting, on other points, the dicta of fellow-inquirers.

This being so, we cannot expect architecture to be any exception to the general law. It cannot command public interest if it ceases to be the expression of the wants and tastes of men.

Considering, moreover, the tendencies I have alluded to, can it be seriously imagined that the architecture of the future is to be committed to individual workmen, giving no guarantee of harmony, and owing no allegiance to the superior authority of the architect? The whole teaching of experience appears to be opposed to such a proposition, and to prove that the architect of the future should be not only a skilled artist, but also a man of scientific knowledge, and in harmony with the spirit of his time.

While it is true that we should gain by having our buildings expressions of the variety of interest, caused by the devotion of many minds to the details of the work, it is still essential that there should be a guiding spirit, and this must be that of the architect; the true reform of ordinary architectural practice would be to lessen the oppressive burden of petty business cares, which, under our present system, press daily upon him, and tend to deaden his devotion to pure art.

Every age of the world we live in has its own special characteristics, just as is the case with the human unit, and we misunderstand the teaching of history if we suppose that the outward signs of progress must always be alike, and must be the same in kind and degree as those to which men have been accustomed in the past. The architects of old worked, as we have no doubt, in perfect harmony with the spirit of their times, and we must expect to find that their mission and ours differ widely, according to the variation of circumstances and the characteristics of different ages.

In many respects it may perhaps be asked whether architects, in these utilitarian days, do not work under less favorable conditions than their brethren of old. It is difficult, for example, to approach the composition of a great work of art with a mind depressed by insistance on the "lore of nicely-calculated less or more." In private works, of course, financial consideration must always have ruled; but it is not easy to believe that the great public monuments of antiquity were constructed on this disheartening principle.

We can scarcely expect again to have great architectural triumphs, if the question about any important public work is, not—how shall we get a worthy building? but,—how little can it be made to cost? We cannot fancy the architects of Westminster Abbey compelled to cheapen their design by reducing their mouldings, omitting the diapers and carvings, or leaving out the groined roofs, in order to save expense. It would, of course, be easy to blame architects for failure under such circumstances; but would it be fair to do so?

I only put this question hypothetically; for, though we may conceive that such things might happen in Laputa, we must not suppose that they could occur in a country like ours, so rich and so prosperous, that it is the treasure-house of the world,—a country which provides, moreover, museums, picture-galleries, and a Government department of science and art for the cultivation of the public taste.

Great nations, however, sometimes do little things, and their very greatness makes them impervious to criticism. It has been said that no one but a banker could walk down Lombard street in a bad hat; and in a similar way, it is perhaps only rich communities that can afford to show with impunity a public indifference to art. At any rate, in our own case, artists may be allowed to hope that the spirit of utilitarianism, pure and simple, will never be allowed to be the sole guide of public policy in respect of architecture. It will not be creditable to us if history should record that, with pecuniary resources beyond those of any other time or country, we leave as our contribution to architectural art, public works showing, in their mutilated features, only too evident proofs of a parsimonious origin.

From these possible difficulties of the architect, we will now turn to other considerations. We are often told that a new style is the want of the time, though why this should be required more than a new

language, it is difficult to say. We have, however, to decide if novelty is to be our aim in architecture, or if it is to be archæology. Again, is engineering architecture? and if not, where is the missing link? You will perceive how many sided is the study of our art, and how much it differs in that respect from painting and sculpture. One difference will at once suggest itself, in as much as architecture is a science as well as a fine art.

A painter designs his picture, happily for himself, with no thought of constructional or economical difficulties. The shadows which fall so easily from his brush must be constructed by the architect. The latter must see in his mind the effects which he intends to produce, and must build them up, not on canvas or paper, but gradually and painfully by the hands of others. If the result fall short of his expectation, he has no power of alteration, no facilities for heightening lights, or deepening shadows. He must be an artist in his design, a man of science in its execution. His science, moreover, must be useful, and not merely speculative. Architecture must not only please the senses. She has to justify her very existence by usefulness. Externally, she may indulge in grace of form, limited only by the exigencies of climate, construction, and by durability. Internally, she must accept the necessity of being bound to combine convenience and fitness with beauty. The arts of design and of building must not clash; but their combination should give a sense of propriety and repose. They should, in fact, illustrate the lesson which Mr. Weekes taught us so well a few nights ago with respect to sculpture, that "beauty is utility."

Architecture must then contrive and construct its artistic effects, remembering always that they must grow naturally out of the circumstances of each case, and that the greatest art conceals its modes of operation. Nothing can be worse than the obtrusion of details, obviously not required, except for display, sacrificing the higher qualities of art to a pretentious fussiness.

Without ornament, indeed, architecture as a fine art does not exist. Nevertheless, though ornament may be essential, it must be an integral part of true architecture, not a mere *applique*, like the beauty patches of the court ladies of Lely or Kneller.

It follows, therefore, that architecture must be studied by those who would practice it, both as a decorative art and as a useful science.

If to some architecture may seem to be degraded from the position of a fine art by its utilitarian associations, it must not be forgotten that to this circumstance it owes much of its attractiveness to all sorts of people. It may, therefore, be well briefly to consider this phase of the subject, and to pause for a moment in order to examine the grounds of interest which architecture possesses for various minds.

We shall find that it has many charms for many votaries, and that it may be studied for various reasons, and from different points of view. Thus, for some its interest is mainly archæological or historic; for others, scientific; and for others, purely artistic. Of these, the archæological is, perhaps, the aspect which is most common; for who is there so indifferent as not to care for the greatness of the past, and the proud deeds of ancestors? The sentiment of innate patriotism alone forbids that national monuments of architecture inherited from antiquity, and handed down from age to age, should be allowed to perish; and it is, therefore, natural that we should find that a certain archæological knowledge is prized as a necessary part of the acquirements of educated men. Indeed, some sort of archæological taste may be said to be universal, for even in the most savage tribes, traditions and ancestral "customs," often, as we know, of the most horrible nature, are practiced and venerated simply for their antiquity.

This kind of archæology is, of course, far removed from art; it interests itself in objects of antiquity because of their age, and not because of their beauty or artistic value; it seeks only to satisfy those cravings for a knowledge of the past, which are as much a part of our nature as the yearning to discover the secrets of the future, which has always pervaded every people, nation, and language.

In architecture, archæologists find a fruitful field of inquiry, apart altogether from any search after beauty. Heraldry, for example, one of the most important of archæological studies, is so allied with architecture that it is difficult to study it without, at the same time, learning to appreciate architectural forms, and the various gradual modifications of them, which have been brought about at different dates.

Thus, to mention only a trifling instance, the shape of the shields on tombs will serve to mark the date of the monument; and no archæologist would confound the early twelfth-century shields of the Knights Templars in the Temple Church with those which abound in Henry VII.'s Chapel at Westminster. In the one case there is a long and simple acutely-pointed triangle; in the other, more complex curves, and a width nearly equal to the height. This, of course, is more an archæological than an architectural detail, but it may be referred to as showing the importance to the archæologist of observing architectural forms; and such observation would naturally lead up to the more extended inquiry of the architect into those gradual changes of the shapes of columns, arches, window tracery, and the like, which mark so clearly the step by step advance and decline of Mediæval architecture in this country.

In nothing has our time been more remarkable than in the impetus given to archæological inquiries, and there are now few parts of the country which do not display results of the activity of those who have interested themselves in the architectural remains of past days.

This archæological taste has found its chief vent in the very remarkable revival of Mediæval church architecture which the present century has witnessed, and to which I shall have to return in my next lecture. A movement partly theological, partly archæological, has covered the country with restorations, and new works carried out in the spirit of restorations. The expenditure on our cathedrals and old parish churches has been enormous, and besides this, new Gothic churches, school, and buildings, chiefly ecclesiastical, have arisen as if by magic around us.

This circumstance is the more remarkable, when we contrast with it the comparative apathy on such subjects, of France, and the continent of Europe. It is also noticeable, as having occurred at a time when free thought is pushed to its utmost limits, and when, in most things, men are apt to regard the past with unquestioning reverence.

If we ask, however, how far the revival movement has forwarded the interests of art, the answer is not quite clear, and probably the time is hardly come when a complete answer can be given. A great measure of success has doubtless been obtained from an archæological point of view; but it may be hoped, rather than asserted, that a greater insight has been gained into the true principles of architecture, which may lead it to progressive glories hereafter such as those that have been chronicled in the past. To critical observers, who regard this state of things with impatience, and are ever calling for novelty and revolution, it may however be suggested that a knowledge of the past is the best education for progress in the future, and that after the period of artistic darkness which marked the commencement of the present century, it was inevitable that any earnest revival should assume an archæological complexion. It may be that this powerful force has now spent much of its power; and it is certainly difficult to see how revivalism, pure and simple, can go much further than it has already done; but the question still remains whether our art in the future is to be based on Mediæval principles, to which alone some would bid us look for the secret of success.

If this is to be the case, it follows that no other style should be cultivated. Is this a conclusion that can be accepted, with the evidence around us, of what the revival has done for us? Is it consistent with the development of the sister arts, in all their fulness in connection with architecture? May it not rather be due to an exaggeration of that archæological study of which we have been treating, pushed beyond the point at which it ceased to act as a trustworthy guide? It is the more necessary to guard against the fascinations of a purely archæological view of architecture, from the circumstance that our Mediæval revival has been from the outset very much mixed up with questions of religion and ritual. These matters can of course be only barely alluded to here; but it is necessary for the student to keep them in mind, if he would understand clearly the history of the powerful movement to which reference has been made.

Architecture has in all ages been intimately connected with the religions of mankind, and the great monuments which remain to us are for the most part the result of the devotional feelings of those who erected them. Thus we have the tombs and temples of Egypt and India, the temples of the Greeks, and the cathedrals of the Middle Ages. It was natural, therefore, that any great religious revival should show

itself in our architecture. In addition to this ecclesiastical influence, there has also arisen a keen desire to inquire, more minutely than has hitherto been usual, into daily details of past history, and historians have sought to give us careful pictures of the manners and life of olden times. No one pursuing such researches could neglect architecture, which yields the most valuable result, when studied in connection with the history of people and countries.

It will thus be seen that to archæologists architecture offers a very storehouse of treasures, and that in that great study of mankind which we call history, the architect, the antiquary and the historian work hand in hand.

We have now to consider yet another mode of viewing architecture, distinct from archæology, and having little or no reference to its artistic character.

Architecture being, as has been said, a science as well as a fine art, we cannot afford to neglect the attractions she presents to scientific men. Science being essentially progressive, we might fairly expect architecture, in so far as she leans on science, to be progressive also; and the complete separation of what we call engineering from all sympathy with architecture, is a fact which is rather suggestive than satisfactory.

In seeking to forecast the future prospects of architecture, it is impossible, therefore, to overlook its scientific and mechanical, as distinguished from its archæological and artistic qualities. No one can doubt that in our time these characteristics of our art will be full of interest to many who, in other respects, care little about it. They will dwell upon the fact that architecture is a useful art, and has no *raison d'et re* except her powers to serve the necessities of mankind. To these the science of building offers special attractions. How was it that nations on whom we are apt to look down have carried out works the difficulties of which excite even now our wonder and admiration, in spite of our greater mechanical knowledge?—works, dating, moreover, from what may be termed the infancy of the world? Is our greater mechanical progress only to drive out beauty and enthrone utilitarianism?

The great monuments of Egypt, for example, are sufficient to raise numerous questions of the greatest interest from this point of view—Egypt, whose pyramids, temples, and colossi seem to regard the works of the engineer of to-day, which are now being urged on around them, with the contempt of a mighty unchangeable monarch for an upstart of yesterday. Here indigenous architecture seems to have died out, and Western civilization is represented by the shriek of the locomotive in the silent wastes of the African desert.

Few things, again, can be more interesting and suggestive than to study the influences of climate, race, and habits, on architectural forms, and to notice how construction has given birth to beauty—as, for example, by the introduction of the arch, the use of columns, bold projections to shelter from the rays of the sun, etc. These may all be termed the utilitarianism of our art, and are as interesting to the engineer as to the architect; but you will see how closely they are connected with artistic beauty, and how necessary it is for the architect to accept frankly and thoroughly the conclusion that his art must be accordant with the laws of convenience and common sense.

How far this conclusion may be carried is the problem before him. Make convenience the absolute ruler, and the result is the ugliness and barrenness of modern engineering. Depose it altogether, and our art will become the laughing stock of a world fully alive to all the advantages, though perhaps not a little deaf to the dangers of a highly-wrought and mechanical civilization.

Engineering may almost be said to have discovered the use of iron, as employed for construction in these later times, and in the choice of materials, the architect must, in any case, be influenced by scientific considerations. Materials, moreover, govern design. Assuming that the principles of the design of the Parthenon are based upon traditions of wooden construction, we can see that the modifications of size and form of the various parts which have been adopted in marble, were the necessary consequence of employing a different material. This principle of using fitting materials, and designing accordingly, was never better carried out than by the mediæval architects of our own country.

Thus, in districts where stone was good and abundant, we find groined roofs and elaborate masonry. In places where timber was the best material available, we see the curious timber constructions, and the beautiful open roofs which distinguish the architecture of Cheshire, Lancashire, Worcester-

shire, and some other English counties. The brick architecture of North Germany and Belgium will also readily occur to you as an illustration of this principle, and you will see how our art, in its best days, has always recognized utility. We may be sure it must always preserve this character if it is to retain the respect of mankind.

In the aqueducts of ancient Rome we have a proof that it is not necessary that an engineering work of the most utilitarian character should be tasteless and ugly, and there can be no reason why the architect should not sympathize with the engineer, quite as thoroughly as he has been accustomed to do with the archæologist and historian.

It is, however, the merit of architecture, that while admitting to the fullest extent, the varied interests to which I have referred, it possesses yet another, the greatest and most comprehensive of all, in its artistic character. The mother of art, it welcomes under its roof all that can claim fellowship in that glorious brotherhood. Indeed, architecture cannot be said to discharge its true mission as a fine art in its fullest sense, except in alliance with its two sisters of sculpture and painting.

This consideration can hardly be too emphatically insisted on as regards its bearing on the style of the future, of which we hear so much nowadays. With regard to this combination it must always be remembered that architecture, like music, is a conventional art, while painting and sculpture are imitative arts. Nature must ever be, in a greater or less degree, the teacher and judge of the latter; while architecture can be referred to no rules but its own, and to that subtle sense of beauty and fitness which is implanted in the human breast. It is this instinct, refined and cultivated by art, which forbids that we should be satisfied with the bare provision for our wants supplied by engineering, and makes us desire some grace to be added to the simple necessities of structure. To add this grace without affectation or untruthfulness is the duty of architecture as a fine art, and her work must not only display beautiful detail, but also fine proportions. It is but too common to overlook the absolute necessity of good proportion, and to rely on ornament alone. This dangerous tendency has been, perhaps, somewhat fostered by the greater attention lately given, and rightly given, by students to free-hand drawing. It is a tendency to be carefully watched, as it easily leads to abuses. Nothing can be subtracted with impunity from a perfect work of architecture; but it can better suffer a loss of its ornamental details than an injury to its proportions.

The Greeks were probably the greatest masters of proportion the world has yet seen; but the tendency of our own later time has too often been to ignore this important quality, to the loss of refinement and of true architectural grace. Perfection of proportion does not mean, however, neglect of scale, as is sometimes erroneously supposed. We have all heard it said that St. Peter's at Rome looks smaller than it really is, in consequence of the harmony of proportions; but this is, in my opinion, altogether an erroneous and misleading statement. If St. Peter's does not impress us with its real size, we must seek the reason elsewhere than in its good proportions, for it can be no merit in a great architectural work to efface itself. An architect is not to be thought successful, if the gross result of his employment of great opportunities is only to produce at a vast cost, the impression that would be created by lesser efforts. The real truth about St. Peter's is, not that the proportions reduce the apparent scale, but that the harmonious effect of the proportions is marred by incongruous detail and fewness of parts, all on a gigantic scale. The enormous order and huge figures, and not its beautiful proportions, have to answer for any disappointment with St. Peter's. If the parts of its architecture had been smaller and more numerous, with its general proportions remaining as at present, St. Peter's would have appeared, as it is, one of the largest buildings in the world; and the interior, more particularly would have gained the effects of scale without losing those of proportion which it now possesses.

The student will learn from this example that he must not be satisfied with the sensation of pleasure, or dissatisfaction, which he experiences when face to face with great monuments of architecture; he must inquire the reasons of their success or failure, and seek to define the secret of the harmony or incongruity of their details and proportions.

To those who study architecture in this spirit, beauties will be revealed which are hidden from the mere utilitarian observer, and they will at the same time gain an in-

sight into the difficulties as well as the resources of their art.

Owing to the universal interest which architecture possesses, we find that it can attract the unlearned, probably to a greater extent than the sister arts are able to do.

The grand effects produced by scale alone may often suffice to explain the impression produced on the minds of the multitude, by an art which does not work in aristocratic seclusion, for the benefit of the few, but appeals openly to the many. Of course, it will only be the few who are qualified, by study and knowledge, to speak authoritatively on its inner subtleties, and its broader characteristic must always be those that will interest the uninstructed observer.

To be able to see properly will ever require education, and the power to criticise is not an instinct, although the power of grumbling may be so. There can be little doubt that an art so essentially conventional as architecture can only be fully appreciated by those who have acquired an insight into its principles. Whether in respect of painting, sculpture, or architecture, whatever there may be of instinctive appreciation in individuals, the power of sympathetic criticism can only be gained by knowledge. In fact, in these cases there is room for what may be called the science of art,—science being, after all, only the concentration of the existing accurate knowledge of any given subject. Indeed, even in observing nature itself, men find the advantage of acquiring instruction, although it might have been supposed that enjoyment of her charms would be a thing of course. There cannot, however, be a doubt that this feeling has varied greatly with different races, and even with different generations, of the same race. Those who know Mr. Ruskin's descriptions,—say, for example, his analysis of clouds, trees, and mountains,—will see how much increase of pleasure in the beauties of Nature herself may be gained by a scientific study of her phenomena, which forms, in effect, the art of "how to observe." Knowledge, then is required in the critic as well as in the artist, and where it abounds a genuine criticism is of the highest value.

It points out to the younger aspirants the way of progress, and exhibits the moderation and diffidence which accompanies true knowledge. It is, of course, free from that arrogance and bitterness which has led the present Prime Minister to refer to critics as "those who have failed in literature and art."

I have now touched lightly upon the interest excited by architecture in its threefold aspect,—archæological, scientific, and artistic. The latter quality is that with which we have chiefly to deal in this place, but the others must not be neglected. There can surely be no reason why architectural progress should be regarded as at an end, when we consider the permanent interests which she has in her keeping. Whatever changes the future may bring forth, the art of building must ever be a necessity, and there will always exist tastes, and artistic aspirations, which will refuse to be satisfied with bare engineering. Architecture, then, must ever have charms for all; reserving the greatest enjoyments for those who, having learned to observe properly, can enter into the inner sanctuary. It is not necessary that she should demand an unanimity of taste, which, if possible at this stage of the world's history, would be undesirable; and she is, therefore, able to rely on that universal love of beauty, to which, after all, must be the final appeal of art.

We have seen that there should exist among civilized men an interest in architecture, which while exerting varying degrees of attraction on different orders of minds, would yet lay claim to a catholicity denied to other developments of the artistic faculty. To the archæologist she offers the key by which he can open the stores of knowledge of the past; with the engineer, she will cooperate in working out the destinies of the present; while to the artist, whether painter, sculptor, or architect, she gives a welcome, and displays treasures of exquisite beauty and infinite variety. Moreover, striving onwards for the future, while reverencing the past, she does not hoard her charms in any churlish spirit, but throws open her treasures to all the world. She connects herself naturally with the history of mankind, with the public and private life of nations, with their knowledge and progress. She has ever been the handmaid of religion,—the nursing mother of art.

Such has been architecture in the past. What is it to be in the future? Are its triumphs over? Are we to be content with the copying of barren revivals? Surely this can not be. All sense of artistic beauty has not vanished before the steam-engine. On such of you, gentlemen, as have just entered, or are about to enter, the noble

profession of architecture, these questions will press, and from you will require a solution. If they are to be answered satisfactorily, there must be no half-hearted devotion to your art. Moreover, in these days, far more even than in those of Vitruvius, an architect should not be the mere master-mason, to which some writers would seek to reduce him. No one can afford to lightly estimate the value of general culture, and certainly not the architect, as a member of a responsible, difficult, and learned profession.

Remember the catholicity of art, which forbids bigoted intolerance and opinionated dogmatism. Study carefully for yourselves the remains of ancient masterpieces in our museums, and in the grand old buildings both abroad and at your doors, and avail yourselves fully of the facilities which are offered in this place and elsewhere for free-hand and figure drawing.

As regards science, do not let it be said that architects are behind the age, but qualify yourselves to take your part in it with knowledge, enthusiasm, and integrity.

Great characters lead to grand ideas; noble thoughts produce noble deeds; and if you will bear this in mind, my first professorial lecture will not have been given in vain.

THE EDUCATION OF CIVIL ENGINEERS.

By THOMAS C. CLARKE, C. E.

Transactions of American Society of Civil Engineers.

Men's characters are the resultant of two factors, birth and education—education, used in the broadest sense of the word, and meaning the development of all our faculties, both by instruction or the education of the schools, and by that larger education of the world which comes from experience and practice.

Some men are born with such great natural abilities that they educate themselves in spite of adverse circumstances and become leaders by the sheer force of genius. But such men form the exceptions and not the rule. Most of us are quite as much, if not more, indebted to education for success in life, than to our natural powers, and it is of the education of this class for that profession or art which we call Civil Engineering, which I have to speak.

The methods of this education used in this country and in England differ materially from those on the continent of Europe. Here we begin by a course of study at some school, college, or technological institution, and complete our education by serving as assistants on some class of public works, for which we receive more or less payment. In England, the course is the same, except that there boys begin younger and with less perfect theoretical education; then they serve their time under some practicing engineer from three to five years, and pay him a premium of £300 to £500 for the privilege. This they do, because their chance of future employment depends on being personally known to some engineer in large practice. On the continent of Europe, practical training by serving on public works as an apprentice to some engineer is unknown. Education begins at the other end, by the compulsory acquirement of a high degree of theoretical knowledge. Partly with this and partly afterwards, a certain amount of practical information is given, but the leading idea is to make a man a thorough engineer theoretically before he begins or is even allowed to practice.

In this country, the tendency, of late years has been towards the continental methods. We have attempted with a wise eclecticism, to combine the advantages of both systems, and educate our engineers in the theoretical principles of the science first and then let them acquire practical knowledge by practice itself.

The important question for us to consider, and to which I wish to call your attention to-day, is, whether a classical education should be combined with a purely scientific course or not, in that earlier part of engineering education which is got in the schools. We can answer this question only by considering what is the object of education at all?

It is to enable us to know ourselves and to know the laws of nature. To know ourselves, we must know the capabilities of the human mind, and this will best be found in the literatures of nations. To know the

laws of nature, we must study the physical sciences. The study of letters is the history of the development of human force and will. The study of nature is the study of those forces which lie outside of human will.

It is the office of the engineer to subdue these forces by human will for the benefit of man—or as the motto of the British Institution of Civil Engineering has it, "Civil Engineering is the art of directing the great sources of power in nature for the use and convenience of man." Man and nature, then should be his study. These are the views of Matthew Arnold, who strengthens his own authority by the opinions of other distinguished educators. My own experience coincides with this; observation has shown me by numerous instances, that those persons who have come to the study of Civil Engineering after a thorough training in both natural science and also, to use the good old expression, "the humanities," are those who make the most rapid progress. When a man has learned how to learn, he can quickly learn anything.

The limits of this paper will not allow me to point out in detail the course of studies which should, in my opinion, be pursued. But I may say generally—it is of the greatest importance that what Bacon calls "the relative values of knowledges" be understood, and not too much time be given to one class to the exclusion of others. The mistake of classical teachers is, that they value grammar higher than literature itself. On the other hand, the mistake of teachers of science is, that the mathematics preliminary to a knowledge of the laws of nature, is valued higher than the knowledge itself.

Much time is wasted in our colleges and technological schools over the higher mathematics. Every engineer here will agree with me that the cases where the use of the higher calculus is indispensable are so few in our practice, that its study is not worth the time expended upon it, and we have the highest authority for saying that unless its use is constantly kept up, we become too rusty to use it at all. Unless the student possesses an extraordinary genius for mathematics, I would limit its study to the ordinary analysis.

The time saved I would devote to the study of natural science in some of its branches. What is it? It consists of observations of facts and the relation of phenomena, of drawing conclusions from the data thus acquired and of finally verifying these conclusions by observation and experiment. This is the best mental discipline, for it strengthens both the observation and the judgment. It teaches patience, accuracy and a love of truth for its own sake. I see no reason why the study of the properties of all materials of construction should not be made a branch of natural science, and studied, not alone by taking for granted what the books say, but by observation and actual experiment.

The curriculum should include the study of both ancient and modern languages; the object being to read and understand what is written in them and not to be a philologist. But let it not be forgotten that the study of our own noble language is worth that of all the rest put together. Indeed it is not sure but that the greatest advantage that we derive from the study of other languages is, that it enables us better to understand and appreciate our own. In regard to style and expression, any man who can think clearly, can write clearly. The best style is that which conveys my thoughts to your minds by the line of least resistance.

Let us now suppose that our student has finished his college course. Instead of entering the technological school, I think he should at once go into the field and the office, and learn the actual practice of his profession. His training will have given him the power of generalizing and he will be able to see the principles which underlie all classes of practice, and to distinguish what is most necessary to be learned. He will very quickly find out the reason why things are done. After some time spent in this way in getting experience of how the affairs of the world are really carried on, not how they are said in books to be done, he may, if he can spare the time, go back to the technological school. His practice will have shown him his own weak points and the "relative values of knowledges" taught there, and he will lose no time, but apply his whole force to that which he most needs.

The practice of Civil Engineering is now so much specialized, that by this time he will probably have selected the branch that he means to follow. That branch is the one that he should study in the technological school. Then comes the time, when the

value of knowing one thing well, will be appreciated

If his abilities have obtained for him valuable employment or connections which he is unwilling to break up by going out of business and back to school, he can pursue the special branch of technical knowledge he requires, either by himself or with the aid of a private tutor. If, for example, he takes up one of the branches of hydraulic engineering, let him concentrate his mind upon the science pertaining to it. If he prefers iron bridges as his specialty, he can find occupation for all his powers in studying the application of statical laws to this class of structures.

By this means, whatever he tries to learn he will probably learn thoroughly and well. On the other hand, if he attempts to cover the whole field of applied science, he will have a smattering of many things and have nothing well.

To recapitulate—let the earlier studies tend toward developing the mind of the student, strengthening his powers of observation and judgment, and teaching him to generalize. Then let him go into the field and study actual practice, select his special branch, and acquire the technical scientific knowledge necessary to the practice of that branch. Let him learn general principles in the schools and technical knowledge while in practice.

But a few days ago the greatest of American railway managers and engineers passed away from among us. The life of John Edgar Thomson teaches us some things which it is well to consider.

1. It teaches us first the value of concentration. He gave his whole mind and heart and soul to his business. As has been well said: "It was his birthright, his education, his pride, profit, and amusement," and well did it repay him for his pains.

2. It teaches us the value of training. The method and discipline of his early engineering studies and practice were of the greatest value to him when conducting the larger operations of his mature life. His knowledge of the value of that training has been shown by the kind of men whom he has left as his successors.

3. We see that no man can hold the position that Mr. Thomson did without a very broad and general grasp of intellect. He may be a specialist and know some branch of his profession much more thoroughly than the rest; he must have much special knowledge of the details of all its branches; but all this will avail him nothing unless he has the power of generalizing, which enables him to look at his business as a whole and appreciate the relative values of all its different parts. And this power is naturally given to but few men, but in all it can be vastly increased and developed by the power of education.

I will conclude this paper by recommending the young engineer to take for his motto those noble words of Prof. Clerk Maxwell: "Accuracy in measurement—truth in statement—and justice in action; our noblest attributes as men, because they are the essential constituents of the image of Him, who, in the beginning, created not only the heavens and the earth, but the materials of which heaven and earth are made."

REPORTS OF ENGINEERS' SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS.—The Society issue this month the following circular:

At the last Annual Convention, on motion of Mr. J. Dutton Steele, it was—

"Resolved, that a committee of three be appointed to inquire into the various systems of signals in use on the several railways of the United States, and to report upon the same to the next Annual Convention, with such recommendations as may seem important."

Messrs. J. Dutton Steele of Pottstown, Pa., O. Chanute of New York, and Charles H. Fisher of Albany, N. Y., were appointed such committee.

The question of signals has, for quite a number of years past, occupied the attention of railway engineers and managers. In 1866 a very interesting report on this subject was made by Mr. Ashbel Welch, to a railroad convention at the St. Nicholas Hotel, New York. In 1871 a code of signals, rules and regulations for operating railroads, was jointly agreed to by a committee of railroad officers, and the Board of Railroad Commissioners of Massachusetts, which was subsequently adopted in 1872 by the Western and Southern Railway Association, now the Railway Association of America.

Notwithstanding these efforts, there is yet such diversity of practice upon the railways of the United States and Canada, as to produce considerable confusion and to lead sometimes to deplorable accidents.

The employés of the various railway lines come into such close relations at junctions and crossings, and so frequently change their service from one line to another, that it seems important the utmost uniformity possible should prevail in all matters pertaining to the signals and movements of trains.

The committee, therefore, proposes to collect all information on the various systems of signals now in use upon the railways of this country, and to

co-operate, so far as it can, in promoting uniformity of practice in this respect.

Will you be kind enough to send us a copy of your rules and regulations concerning signals, whether embodied in your time-table or book of instructions, together with a detailed statement of such signals as you may wish to call particular attention to, under any of the following heads.

General, or train signals with the steam whistle, the engine bell, the train rope, the hand lamp, the arm and hand, flags, torpedoes, fuses or fire tubes.

Signal systems by towers, scimaphores or vanes, automatic telegraph.

Special or fixed signals at junctions of railways, grade crossings, switches, stations, tunnels, drawbridges, inclined planes, switch backs.

You will much oblige us if you will send an explanatory sketch of such of these as may require it, drawn in black lines on a scale suitable for publication in the Transactions of the Society.

The committee will feel especially obliged in receiving a description of any system of block signals, either mechanical or telegraphic, which may be in use, or favored by you, together with an account of its workings and of the advantages expected, as well as of any interlocking gear and signals to regulate the entrance and departure of trains at any large station.

It is also desired to know what system of signals would be most applicable to a triple or quadruple track railway, in which certain tracks would be used exclusively in one direction.

Please direct replies to the Chairman, Mr. J. Dutton Steele, Pottstown, Pa.

Respectfully, J. Dutton Steele, O. Chanute, Charles H. Fisher, committee.

IRON AND STEEL NOTES.

THE IRON ORE OF LABRADOR.—About eight years ago it was discovered that there existed on the north coast of Labrador, large quantities of magnetic iron ore in sand, but for a long time no one could be induced to seriously take in hand the working of the mineral wealth, whose existence was undoubted. It seems, however, that the time has come at last when those who, for eight years past, have vainly endeavored to find a market for this magnetic ore, which lies in such abundance on the north coast, will see their efforts crowned with success. This species of sand has been known for several years, but to Mr. Lamothe, of Montreal, who accompanied the Southern raiders in their flight, is due the honor of having contributed to their working and development. A company was formed, and forges were built at Moisie. These works have been in operation ever since. A short time was sufficient to show that magnetic sand was to be found not only at Moisie, but almost all along the north shore. The richest deposits are, however, at Matashquan, Kegashka, St. John River, Moisie, and St. Marguerite. Other deposits are also found elsewhere, but not of such considerable importance. Several experiments have been made to purify this sand in a rapid and economical manner, and to make steel by the direct process. Both these problems have been solved. The secret of purifying we owe to Prof. Larne, of the Laval University, and the other we owe to Mr, Labreche Kiger (now deceased) of Montreal.

Two young gentlemen from Quebec, placing great hopes in this new industry, have induced some English manufacturers at Swansea to buy this black sand when prepared. They began in June to put up the necessary houses at a place called Black Point, between St. John's River and Mingau, and twenty-three men have ever since been constantly employed in preparing the sand, which contains in the rough state 30 per cent. and when prepared 99 per cent. of magnetic iron ore. These men prepared ten tons of it per day last summer, but arrangements are being made by which thirty tons per day can be prepared.

The experiments already tried for the fabrication of steel, and the quality produced, give sufficient security to rely on the success of this undertaking. Quebec has established a factory for the fabrication of steel from this sand, and Messrs. Duval and Michaud have already sent up several tons of the ore to that city. At Matashquan, also an establishment is being put up. The richness of the ore discovered in Labrador excels the similar deposit at Taranaki in New Zealand; and there is every indication that the industry thus developed will rapidly extend and become an important item in the commerce of the province.

COMPOUND CUPOLA FURNACES.—A cupola furnace has lately been patented by Mr. Swain, of Manchester, in which an auxiliary reservoir is attached to the bottom of the cupola. The metal as it liquefies, instead of lying in the hearth of the cupola below the tuyeres, is, in this arrangement, tapped off and collected by a passage in an auxiliary chamber or hearth. The advantages of this arrangement are numerous. This reservoir, which can with ease be applied to any old cupola, enables a much larger quantity of metal, compared with the size of the cupola, to be stored up and kept hot, than can be done with the old style of furnace. It gives an easy method by means of which the capacity of any existing cupola may be readily increased to meet a demand for heavier castings. It is also noticeable that the part of the blast producing heat to keep the charge liquid, is not obliged, as in ordinary cases, to pass through the whole of the fuel. Thus a considerable economy is claimed to be effected. The fuel used being simply that required to effect fusion, the fusion being afterwards kept up apart simply by the hot blast, and the oxidation taking place in the bath itself. The advantages that the inventor claims are as follows: (1) the fusion takes place more rapidly, and the weight tapped is much greater than under the old system; (2 the passage of the hot blast over the surface of the liquid metal, facilitates the oxidation of all impurities contained in the metal; (3) the liquid metal is heated more strongly, and is better mixed; (4) there is economy of time; (5) large masses can be cast with the same ease as small ones; (6) a considerable economy of fuel is effected; (7) the liquid metal can be retained, and be kept hot for a considerable time, in fact, the action of the reservoir has all the effect of refining, the silicon, sulphur, and phosphorus being largely carried off in the bath. The same cupola and reservoir may also be applied for the fusion of pig iron for puddling. The

liquid metal will run then directly from the reservoir to the puddling furnace, and thus save the reheating. This would represent a large economy over the ordinary methods. Another advantage is obtained in the reduction of the expenses in repairs to the puddling furnaces, caused by the reduction of the pig iron on the hearths of those furnaces, since if the metal is introduced in a liquid condition into the furnaces, the production of iron is doubled in a given time, the expenses of repairs and interest on capital are all halved.

RAILWAY NOTES.

AUSTRALIAN RAILWAYS.—The demand for our railway iron in the Australian colonies has been highly encouraging this year. Month by month this demand has grown larger and larger. In August it amounted to 10,031 tons, against 2,295 tons in August, 1873, and 1,993 tons in August, 1872; while in the eight months ending August 31st, this year, it amounted to 55,252 tons against 13,304 tons in the corresponding period of 1873, and 14,577 tons in the corresponding period of 1872. There seems little reason to suppose that the Australians will for many years to come be able to provide for their own rail consumption; and as the activity prevailing in the development of Australian railways is very marked and decided, we shall, in all likelihood, make liberal rail deliveries to Australia for, at any rate, the next five years.

The latest intelligence to hand from the Australian colonies shows that the locomotive is gradually extending its operations in those interesting dependencies. As regards Victoria, it may be observed that the line from Castlemaine to Maryborough, and the first section of the Ballarat and Maryborough line, from Ballarat to Creswick, were opened for traffic on July 7. The Castlemaine and Maryborough line was commenced in September, 1872, and was one of the light lines authorized by the Victorian Railway Construction Act, 1871. The length of the line is 34 miles. The line from Maryborough to Dunolly is in a forward state, and it will be finished in about two months. The construction of the Ballarat and Maryborough line is also being proceeded with as rapidly as possible; the first section, from Ballarat to Creswick, which has been opened for traffic, comprises a distance of 11¼ miles; the second section of this line, from Creswick to Clunes, a distance of 10¼ miles, will be completed in about four months, and it is anticipated that the line will be finished through to Maryborough in February or March, 1875. As regards Tasmania, the Tasmanian Main Line Railway is being pushed through with great energy, and it has absorbed a very large quantity of rails and accessories. Even now this demand can scarcely be regarded as exhausted. In New South Wales and Queensland we find a great deal of railway activity, and in New Zealand several lines of some importance are also on hand.—*Lond. Mining Journal.*

ENGINEERING STRUCTURES.

THE CHANNEL TUNNEL.—The preliminary steps towards the execution of this stupendous project are being steadily advanced, although the undertaking itself has dropped from the view of the general public. The mechanical and geological questions involved were fully discussed in a paper read before the Society of Arts in March last, fully reported in our columns at the time. They have been considered with much care by the advisers of the committee of promoters, Sir John Hawkshaw and Mr. Brunlees. The grey chalk—a mass of strata 500 ft. thick and impervious to water—which forms the principal mass of the cliff at both Dover and Calais, strikes across the channel with so little divergence from horizontally that a tunnel could be pierced within the vertical bounds of its thickness. To ascertain with exactitude the configuration of its outcrop, and the surface outlines of the other associated cretaceous rock,—numerous soundings and borings of the sea-bed have been made in a most ingenious manner by means of an iron tube, over which a hollow shot, fitting loosely, is raised and let fall upon a flange attached to the tube, the end of which is in this way driven into the substance of the sea-bottom, the core thus obtained giving the required sample of the rock perforated. Some hundreds of these borings have been made, and a geological chart of the Channel constructed from these data. These accurate details of the strata and their outcrops have enabled the most promising line of route to be selected, and which is accidentally very nearly that of the Dover and Calais Submarine Telegraph Cable. The plan and construction of the proposed tunnel has received the joint approval of M. Duroich, M. Bergeron, M. Lavallay, and other associated engineers of eminence. The line of the main tunnel, which is to be large enough for a double line of railway, is drawn straight from St. Margaret's Bay, South Foreland, to a point very nearly midway between Calais and Sangatte.

In longitudinal section the proposed tunnel presents a slight fall of 1 in 2640 from the centre towards either extremity, and the vertical depth of the highest point of its floor is 436 ft. from Trinity high-water mark, and 200 ft. beneath the sea-bottom itself. From the land levels of the existing railways the two approaches make long descents of over four miles, each with gradients of one in eighty, into the tunnel ends, over two miles being under the sea, the total of the whole amount of tunnelling amounting to thirty miles. The greatest depth of water over the sea-bed above the tunnel is stated to be 180 ft. Below the railway approaches, and continuous with the floor of the submarine tunnel itself, there will be at each end a driftway leading to vertical shafts ashore for drainage and ventilation. These terminal shafts and driftings are the preliminary works which it is intended to make as tests for the practicability of the general undertaking, and of which, when completed, they will form essential portions. The shafts will be 19 ft. in diameter, built around with 24 in. of brick laid in cement, and the headings, which will be driven by machine—probably Brunton's—will be lined with 14 in. of brickwork, and have internal diameters of 7 ft. Their form will be horseshoe, with straight sides, and a flat inverted arch below the floor. The estimate for the entire preliminary works—which, to satisfy the *amour propre* of both nations, will be carried on simultaneously in both countries—is, with all expenses contingent on their execution, something less than £160,000, including the two pumping

engines, of 2,000 horse-power each. The total cost of the whole tunnel and its accessories is, for the present, put at £10,000,000; but there are those among the engineers who think the preliminary works will afford data for a much lower estimate.

Considerable progress has also been made in the commercial arrangements. The actual position of affairs at this time is that the *projet de loi* has been prepared, and will be presented on the reassembling of the French Chamber in November by M. Caillaux, now minister of Public Works, formerly a member of the Channel Tunnel Committee —the aspect of this Channel Tunnel scheme having thus changed from adverse under the Government of M. Thiers to conditions not unfavorable under that of Marshal MacMahon. Nothing further can be done until then to advance matters beyond their present position, and of course nothing more substantial is likely to be ever effected until a concession be obtained. The promoters, knowing the cost of the tunnel railway will be ten times that of an ordinary one, not unreasonably seek power to levy fares to say five times the French rates, or a maximum toll of about 5d. per mile—the present steamboat rates being 4d., and the English legal first-class fare 3d. per mile. It does not follow, however, that the maximum fares conceded would be the ordinary fares charged. The Channel Tunnel project is to be carried out by a French and an English company, the general management to be vested in a committee whose members will be furnished by the two directorates. Towards the preliminary engineering works each company is to contribute £30,000, of which £40,000 is definitely promised by the Northern of France; and £20,000 more is added by Rothschild Brothers, of Paris, whose intimate relations with that railway are well known The residue will be contributed by the French members of the promoting committee. With the English company no advance has been made over the original £30,000 subscribed in 1872; but its moiety of the preliminary total it is expected will also be subscribed privately.—*Iron.*

THE WATER SUPPLY OF PARIS.—A correspondent of the *Leeds Mercury* gives the following description of the great works at the Reservoirs of Montsouris: Until these works were completed, the Parisians possessed only 338,000 cubic metres of water, or 1,108,900 cubic feet; that is to say, 140 litres per head. This water comes from the springs of Belleville and the Près St. Gervais, the artesian wells of Grenelle and Passy, the springs south of the city, formerly called "Royal Springs," passing by the aqueducts of Arcueil, the rivers Ourcq, Marne, Seine, and lastly the Dhuis, which is diverted from its course almost at its source, and which made its first entrance into the city of Paris in 1865. The waters of the Dhuis are received in the magnificent reservoirs of Menilmontant on the second story, and comprise 100,000 cubic metres of water, while the first story of these same reservoirs receives the waters of the Marne. It is simply two lakes one above the other. Maxime du Camp justly calls this "a unique construction," for, says he, "when I call to mind the cistern at Constantinople, with its thousand and one pillars, the dam in the Valley of Belgrade, the 'Piscina Mirabile' at Naples, Solomon's wells at Ray el Din, and the cistern of Hezekiah, at Jerusalem, I can find nothing at all analogous, and I believe that in all ages nothing equal to it has been produced. It appears all but miraculous, when we consider its marvellous conception, and the immense difficulties in its construction. It is a triumph of genius and scientific industry." The work has cost 8,700,000 francs, and covers a surface of two acres, and is one-third less in size than that which is now being completed on the heights of Montsouris. In a short time the Parisians will be in possession of an additional supply of water, amounting to 328,100 cubic feet, consequently giving in all 210 litres per head, instead of 140.

We are far indeed removed from the time when François I. had to petition his good city of Paris for a small supply of water, to use the expression of the period, "no larger than a vetch seed," for the use of the Bishop of Castres. In those days 460 cubic metres, or 1,509 cubic feet of water, was the supply for the whole population of the city, and this was in 1669, only two centuries ago. The last of these admirable results was effected by the construction of new reservoirs on the site of the ancient park of Montsouris, for many years the rendezvous of beggars, miscreants, etc. These will be dislodged, another beneficial result of this undertaking.

The great hydraulic works of which I am speaking distribute in Paris the waters of the river Vanne, taken at their source in the Department of the Aube, about 104 miles from Paris, and brought by aqueducts through a pipe of cast iron of upwards of a metre in diameter. This gives 1 metre 10 centimetres cube of water per second, which flows into the reservoirs. These reservoirs are four in number, two on the lower and two on the upper story. They are completely separate, but can be united to each other according to the requirements of the service, or for repairs, etc. It is a perfect forest of pillars made visible by a very peculiar light let in through semicircular air-holes. The shadows cast by the high and narrow arches, in which the water rises upwards of five metres, cause a strange and mysterious appearance which it is difficult to describe, or if once seen to forget. In each section there are 900 columns ranged in thirty equal divisions, making in all 3,600. These columns, as well as the arches and the floor, are made of stone, covered with cement. The columns gradually diminish in circumference until they reach the height of 5 metres 80 centimetres, where the arches commence which unite them. The greatest elevation is 7 metres 10 centimetres. The pillars of the upper story are inferior in height and strength, not being required to support an equal weight of water. This floor will contain only 100,000 metres of water, while the lower floor will contain 200,000 metres. The whole will be covered with 50 centimetres of earth, to be sown with grass, intended to preserve the water from the influence of atmospheric changes. Its external appearance is that of a massive building with but few apertures, and is by no means ornamental. This water will supply the principal quarters of Paris, and will replace that of the river Ourcq, which is in such a filthy condition that the iron gratings through which it passes require to be cleansed three times a day, and during the period of the hay harvest these gratings have to be changed every half-hour to prevent their being broken. This colossal work will cost five million francs—an immense

sum it is true; but will not the benefit also be immense in securing to the population of Paris an almost unlimited supply of pure water?

ORDNANCE AND NAVAL.

TORPEDO EXPERIMENTS.—The third of the series of what are known as the "Oberon Experiments" has taken place. The Oberon was formerly a wooden paddle-steamer, but her bottom has been plated, in order that it may resemble the bottom of the Devastation; and the object of these experiments is to ascertain at what distance from an ironclad a torpedo may be fired without injury to her. At the first experiment, a mine containing 500 lbs. of compressed Waltham Abbey guncotton, saturated with fresh water, was sunk at a depth of 47 ft., and at a horizontal distance of 100 ft. from the starboard beam of the Oberon, which was moored off Fort Monkton. The mine was fired from the fort by electricity, but the ship sustained little or no injury. At the second experiment the distance of the torpedo from the vessel was reduced to 80 ft., but again the ship escaped. The last experiment was under precisely similar conditions, except that the distance was still further reduced to 60 feet. The boats having got clear of the ship, at ten minutes to four the mine was fired. The explosion was followed by a huge column of water being thrown some hundreds of feet into the air, and by much slaughter of fish. On the ship being boarded, a joint of the inlet pipe leading to the condenser from the sea, was found to have been started, and to be leaking, everything movable on board had been displaced, and had she been fully rigged it is probable the upper part of the ship would have been a good deal injured. But, so far as can at present be ascertained, her hull had once more entirely escaped. Some sheep and rabbits left on board seemed none the worse for the explosion. The Oberon w s soon afterwards towed into harbor and docked. On Monday last week she was officially surveyed. The survey resulted in the official conclusion that no damage was inflicted upon the double bottom or the hull of the vessel by the experimental explosion of a sunken mine within a horizontal distance of 60 ft. The slight damage to the joint of the inlet-pipe to the condenser is considered to be solely due to the fact that the condenser is not fastened to the Oberon s bottom in any way, and not at all likely to happen to a condenser fixed in the ordinary way on board all ships fitted for service in commission. At the next experiment, the mine will be placed at only 40 ft. from the ship.—*Iron.*

THE NAVIES OF EUROPE.—The German correspondent of the *Times*, in an interesting article on Prussian ironclads, gives the following comparative list of the vessels of the European navies: —All Europe at this moment has 142 ironclads fit to be placed in line of battle. Of these England owns 38, France 28, Austria, Russia, Italy and Turkey 15 each, Germany 8, Spain 7, Denmark 3, Greece 2. The tonnage of the German ships and the size of their guns are, however, so uncommonly great that, although few in number, they are supposed to be a match for any navy, those of England, Russia and France excepted. Besides these there are 103 iron-cased vessel to be found in Europe for the defense of coasts. Of this number Germany has two; Spain, Norway and Denmark, 3 each; Turkey, 5; Sweden, 9; Russia, 13; Holland, 18; England, 23; and France 30; 431 screw frigates and corvettes make up the wooden array of European strength at sea. Here, again, England, with 132 vessels, 5,670 guns and 50,700 horse power, has the first place. France, the second on the list, records only 52; Russia, 48; Turkey, 44; Spain, 37; Holland 25; Italy, 24; Germany, 17; Denmark, 16; Austria, 14; Portugal 8; Sweden, 6; Norway, 5; Greece, 2. Smaller craft, such as avisos, gunboats etc., of which England alone has 276, with 309 guns, and 13,284 horse power, are not reckoned in this calculation. If England were to man her navy for war, she would require 68,000 men, of whom 22,000 would have to be enlisted for the purpose. Russia for the like object, wants 36,000; France, 33,570; Turkey, 21,000; Spain, 14,000; Germany, 13,000; (every one kept in readiness); Austria, 11,530; Italy, 11,200; Holland, 6,260; Denmark, 4,800; Norway, 3,500; Portugal, 3,300; Sweden, about 3,000. Comparing the total of the German crews with those of the other States, we find it exceeded by England, Russia, France, Turkey and Spain. Spain does not count, so much of her forces existing only on paper; nor can Turkey's numbers be relied upon, she being to a great extent dependent on foreign help for the effective manning and officering of her ships. Hence the German navy is in reality inferior only to the British, Russian and French; and even this statement requires to be qualified, German vessels being much more sparingly manned than either the Russian or the French, and 13,000 German sailors being accordingly not so very much below the strength of 36,000 Russians or 33,570 Frenchmen, as the figures would seem to indicate.

BOOK NOTICES.

ELEMENTARY HISTORY OF ART. An Introduction to Ancient and Modern Architecture, Sculpture, Painting, and Music. By N. D'ANVERS. With a Preface by T. Roger Smith, F.R.I.B.A. Price, $4.00. For sale by Van Nostrand.

It is not an easy task to compress the history of Art within the compass of an ordinary-sized volume without allowing much of what is the essence of such a history to escape in the process. The subject is so large, and requires so much space for its treatment, that when a confined limit is fixed, there is a risk that the result will be little more than a catalogue of names. On the other hand, as painting, sculpture, and architecture are related, it is of advantage for any one about to undertake the study of either to be able to obtain a more or less comprehensive glance at the three. There is no doubt that an elementary history of art has been required, and this Mr. D'Anvers has now given to the public in a compact volume. He has used a popular German treatise as a basis, but has taken care to meet the special requirements of English readers. English art is treated specially, and throughout

he refers to the examples of the work of other countries which are found in the British Museum, the National Gallery, and the South Kensington Museum, and especially among the fine collection of copies of sculpture at the Crystal Palace, and by so doing shows what opportunities are available to those who cannot visit Continental galleries. There are one hundred and twenty excellent German woodcuts in the book—but nearly all are from foreign examples; there are some illustrations among them of English buildings; but there is not one from an English painting or statue. This deficiency might have been supplied without much expense, and the illustrations would then bear a better proportion to the letter-press in the attention given to English art. Unlike certain other writers, the author has no theory of his own to offer as the key to the history of art, and the student cannot therefore be biassed in a way as likely to be injurious as helpful. Although Mr. D'Anvers' book is mainly intended for those who are about to commence the study of art, yet, from its correctness and conciseness, it will be found to be a handy compendium of art history for those who have experience. For general readers, or the great body of amateurs, it will be found most valuable, while the style in which the volume has been produced, renders it particularly adapted for a present or for a prize in schools.—*Architect.*

FIRST LESSONS IN THEORETICAL MECHANICS. By the Rev. John F. Twisden, M. A. London. 1874. Price, $4.25. For sale by Van Nostrand.

Professor Twisden's treatise on mechanics is remarkably clear in arrangement and style. There are also a very large number of examples introduced as illustrations of principles, and which no less become tests of a student's progress. Only a limited knowledge of mathematics is needed in order to follow the author's treatment of the subject. The book may be recommended as an elementary treatise which is both simple and precise.

WORKSHOP RECEIPTS FOR THE USE OF MANUFACTURERS, MECHANICS, AND SCIENTIFIC AMATEURS. By ERNEST SPON. 1873. Price, $2.00. For sale by Van Nostrand.

This volume, which has been published for several months, has merited an earlier notice at our hands as a really remarkable compilation of receipts of almost every kind that may prove of service to those to whom its title page is addressed. But small attempts even at broad classification have been attempted, so that we find the contents of the book somewhat as follows: receipts for mechanical draughtsmen, followed by others referring to metals, cements, dyeing, glass, porcelain, and pottery, varnishes, pigments, painting, masonry, plastering, engraving, firework making, electro-metallurgy, photography, soap and candle making, veneering, marble working, etc. Still by the help of the really very fair index the book possesses, any particular receipt can be selected from the heterogeneous mass, and we must say, in all justice to the author, that when found, the receipts are almost invariably useful, and bear evidence of having been carefully prepared, and submitted to practical criticism before publication. We should imagine, indeed, that the writer must have consulted a great number of authorities, apart from book research, for a large number of the receipts are new, that is to say, they have not been published before, and old ones have been modified, and their usefulness increased.

To add to the value and clearness of the letterpress, a considerable number of small engravings are scattered among the text, and save much space in explanation. We trust that this book has already met with what it deserves—a full meed of success among those for whose benefit it was prepared.—*Engineering.*

IRON AND STEEL. By CHARLES HOARE. A Work for the Forge, Foundry, Factory and Office. Charles Hoare, Southampton.

The book before us gives a very useful collection of notes and tables, and which we can cordially recommend to those engaged in considering the details of all kinds of iron and steel work. The author in his preface supplies an excellent guarantee that his book has been compiled with care and accuracy, and that it is generally useful, when he gives a list of all the leading shipbuilding and engineering firms in the kingdom who have certified their approval of it. And we may further state in its favor that this little work has already passed through six editions, a fact which shows that its utility has been pretty extensively recognized. Many useful hints and rules are given for lessening the amount of arithmetical labor, which is always more or less necessary in arranging iron and steel work of all kinds, and a great quantity of useful tables for preparing estimates of weights, dimensions, strengths of structures, costs of work, etc., will be found in Mr. Hoare's book. The following passage we quote from the author's preface, and the statement he makes in this quotation we can fully indorse, after having carefully examined the data he gives:

"Differing materially, as it does with few exceptions, in the treatment of the various processes, it also contains a greater amount of special information on iron and steel working than can be found in any other book. In this department it has found a province of its own, without trenching on ground so ably filled by Molesworth, Templeton, and other established favorites."

A TREATISE ON THE PRINCIPLES AND APPLICATIONS OF ANALYTIC GEOMETRY, BY HENRY T. EDDY, C. E. PH., D. For sale by Van Nostrand.

We find in Prof. Eddy's new work some features which we have long regarded as important, but which have hitherto been wanting in an American text book suited to Academic and Collegiate students. Among these are, the improved notation of angles, such as is employed by European writers on modern Geometry—A thorough exposition of the general principles of the science set forth in a series of propositions, and Newton's method of discussion of curves and their singularities.

A great number of examples are afforded for

PLATE III.

AUTOGRAPHIC STRAIN-DIAG

ILLUSTRATING THE EFFECTS OF TIME AND OF TEMPE

PRODUCED BY THE

TESTING MACHINE OF PROFESSOR R.

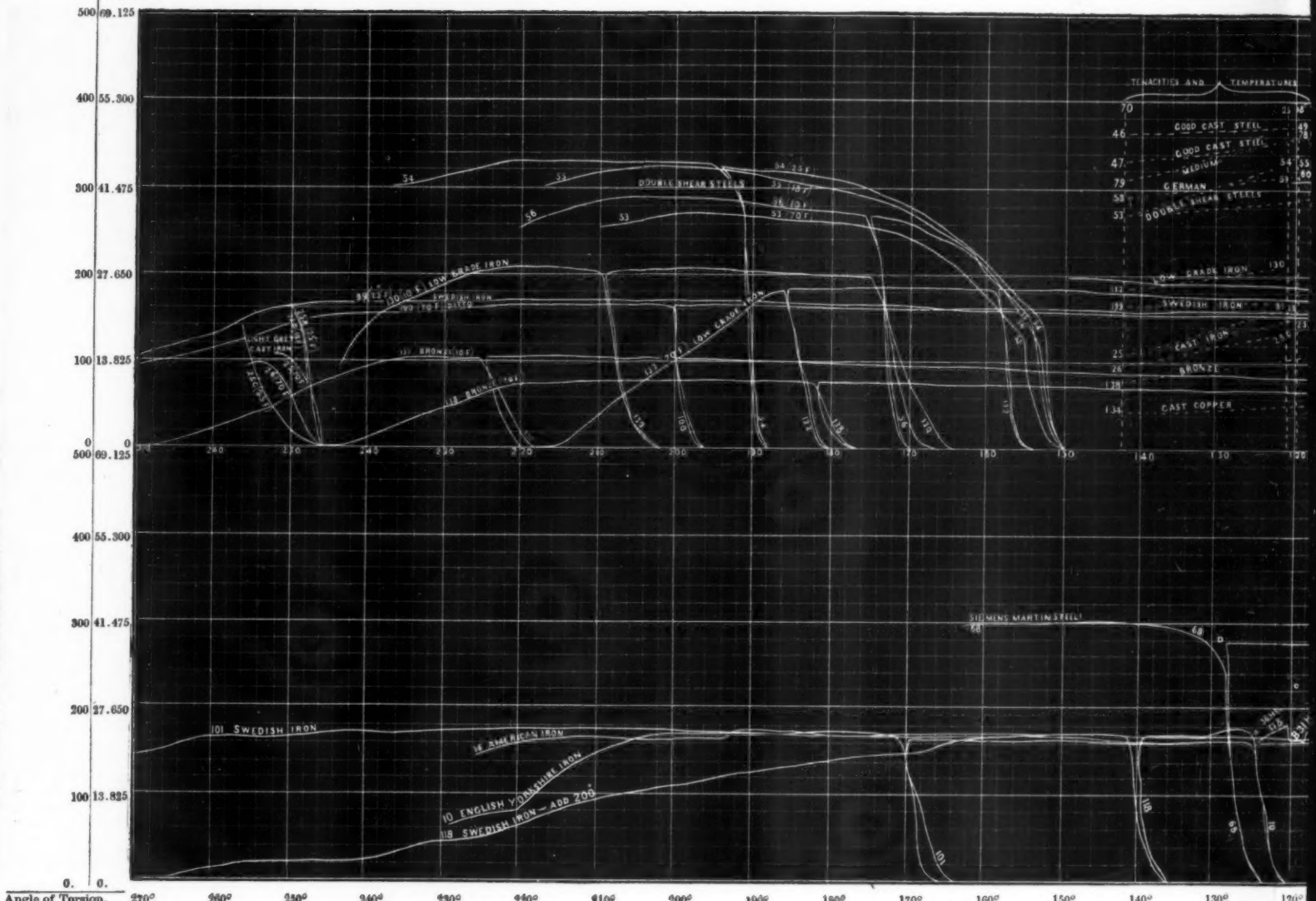


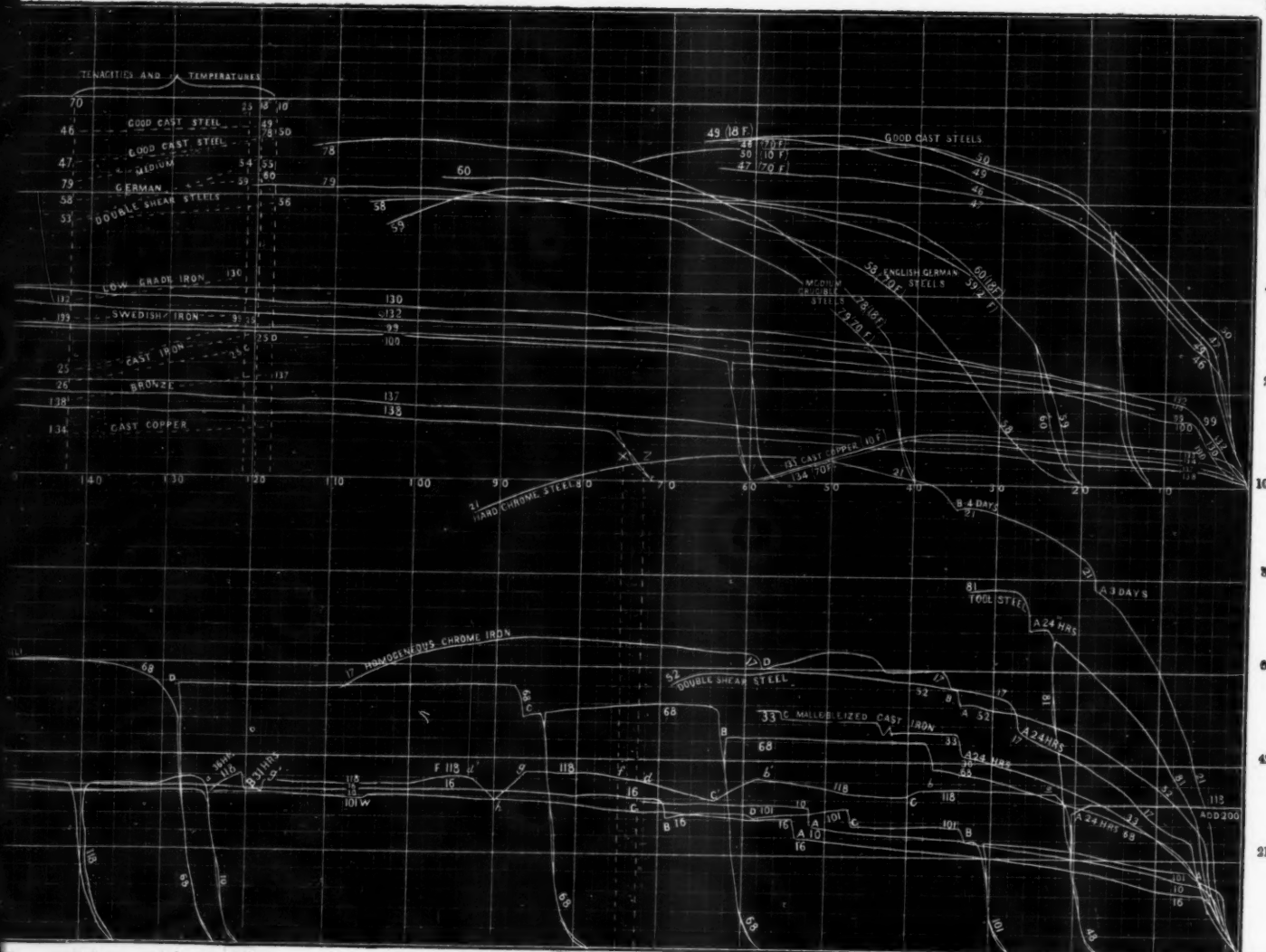
PLATE III.

AIN-DIAGRAMS OF METALS,

S OF TIME AND OF TEMPERATURE UPON RUPTURE,

PRODUCED BY THE

E OF PROFESSOR R. H. THURSTON.



150°	140°	130°	120°	110°	100°	90°	80°	70°	60°	50°	40°	30°	20°	10°	0°
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Ap
Tensile
Kilogramme
per square
Millimetre.
105.46
84.36
63.27
42.183
21.092
0.
105.460
84.369
63.277
42.185
21.092
Angle
Maxim

Approximate Tensile Resistance.	
Kilogrammes per square Millimetre.	Pounds per square Inch of Section.
105.460	150.000
84.369	120.000
63.277	90.000
42.185	60.000
21.092	30.000
0.	0.
105.460	150.000
84.369	120.000
63.277	90.000
42.185	60.000
21.092	30.000

0° Angle of Torsion.

0 Maximum Extension.

practice, and in addition to these frequent so-called exercises are given for the more advanced student.

The typography of the book is excellent.

BUILDING CONSTRUCTIONS; SHOWING THE EMPLOYMENT OF BRICK, STONE AND SLATE IN THE PRACTICAL CONSTRUCTION OF BUILDINGS. By R. SCOTT BURN. 1873. Two vols. London and Glasgow. Price, $1.50. For sale by Van Nostrand.

This is one of the numerous family of text books which many publishers have of late years issued broadcast, and it possesses the common characteristic of this class of work in being elementary and profusely illustrated with coarsely executed sketches. Indeed, besides the cuts in the first volume, which number 180, in 132 small pages, the second volume is made up of twenty plates, nearly the whole illustrating different modes of setting bricks, and to enhance their value the author says, "It is right to state that they have been, with few exceptions, *projected expressly for this work* from examples of small scale bricks laid down specially for our purpose." The italics are not our own.

We think that Mr. Burn might have spared his readers the first chapter on drawing, which is absolutely of no service, being too brief to serve those quite ignorant of the art, and too elementary for any ordinary lad to profit by after he has been a week in a drawing office. Plate I. of the atlas, also, is quite useless, consisting as it does of a number of badly divided scales, the intended purpose of which we do not understand.

Apart from these faults, we believe that Mr. Burn has written a little handbook that will be useful for reference not only to the student, but to builders, draughtsmen and intelligent bricklayers.—*Engineering.*

THE NEW CHEMISTRY. By JOSIAH P. COOKE. New York. 1874. Price, $2.00.

It is long since we read a work on chemistry which has charmed us so much as this of Professor Cooke, and the publishers are well deserving of credit for including it in their International Scientific Series. The mode of treatment adopted by the author is opposed to that of every other elementary treatise we know of, yet for giving a clear idea of the cardinal facts and theory of the science there is none equal to it save Hoffman's lectures on "Modern Chemistry." But Hoffman begins with experiment, and continues with beautiful and well-chosen illustrations to lay a foundation upon which he erects the theories and laws which are now generally accepted as governing and explaining chemical changes. Boldly reversing what the majority of us has always considered the natural mode of building up a science, Professor Cooke starts with a theory, the law of Avogardo and Ampère, and goes on through unaccustomed paths, occasionally throwing in a bit of heresy, *e. g.*, a doubt of the correctness of the wave theory of light—teaching his hearers and leaders certain dogmas in chemical physics, and forcibly impressing them on the mind long before he insists on a single chemical fact proper, or even gives them a single experiment or symbol. The success with which he has treated his subject is the best possible refutation of our previous prejudice against the mode he has adopted, though we are still inclined to think that only the equals of our author can hope to share this success. The book may be read with advantage by those belonging to the same class as the audience before which, in the form of lectures, it was first laid—namely, the intelligent but not professional, the style being lucid and the illustrations well selected. Students will also profit by its perusal, as it will teach them to think, and if they have been exceptionally well drilled in ordinary methods it will do something towards shaking their faith, and thus give them that desirable liberality of mind which holds theories loosely but facts firmly. It may even teach some how to classify facts for themselves—an accomplishment by no means so common among our uniformly manufactured students as it ought to be. We can add no more to our recommendation except the further one to our readers, that they cannot do better than peruse the book for themselves.—*Iron.*

MISCELLANEOUS.

THE THURSTON TESTING MACHINE.—REPORT OF NAVAL OFFICERS UPON ITS USE AND EFFICIENCY. Navy Yard, New York, May 2d, 1874. Vice Admiral S. C. Rowan, U. S. N. Comd't. Navy Yard, New York.

Sir:—In obedience to your order of the 25th ult., that we should proceed to the Steven's Institute of Technology, in Hoboken, New Jersey, and witness the operation of the Machine designed by Prof. R. H. Thurston of that Institute for testing the strength of materials, etc., to examine those in course of construction, to inspect the work already done, and the designs of machines proposed for special purposes, and to report in duplicate the results of our examination and our recommendation in view thereof.

We have the honor to report that, we have visited the Steven's Institute and witnessed the operation of a machine which has for its purpose to subject specimens of different materials to strains of torsion continuously from the initial strain through all the succeeding stages to final rupture; the machine being furnished with an automatic registry by which means the relation between the moment of torsion and the angle of tortion is graphically represented throughout the entire process of any experimental inquiry of the kind. We have also examined several machines in course of construction with improved features in the details of their operation, besides examining drawings of other and larger machines. We are satisfied that this form of Testing Machine admits of being used with great facility in the practical study of the properties of the woods, the metals and their alloys, especially with reference to their elasticity, ductility and ultimate resistance, that it is capable of revealing characteristic physical properties of great value in forming a practical judgment of their relative usefulness under different circumstances of their production or manufacture.

We find the machine an extremely simple one, and as small cost (estimated at $350.00 each), and, while we do not think it can judiciously replace the machines for direct tension, we are of the opinion that this machine would be found quite useful in the different departments of the Navy Yards requiring the kind of information furnished by it.

Signed, Robert Danby, Chief Engineer, U. S. N., W. L. Hanscom, Naval Const'r., U.S. N., Richard W. Meade, Commander, U. S. N.

ISOMETRICAL DRAWING.—At the last meeting of the British Association, Mr. George Fawens, of North Shields, read a paper on a new method he proposes for facilitating this manner of projection.

Isometrical drawing is supposed to represent a bird's-eye view of objects thrown back or forward at an angle of 30 degs. Right angles are thus extended or foreshortened 30 degs. in a manner somewhat similar to perspective drawing of square or cubes, the angles of 90 deg. being thus represented isometrically by angles of 60 degs. or 120 degs., and a square plane being drawn in a lozenge or diamond shape. In order to draw more readily lines intersecting each other at angles of 120 degs. and 60 degs., it is proposed by Mr. Fawens to use equilateral triangular-shaped boards with the ordinary T-square applied to the edges of the three sides. In an isometrical drawing these three sides will give lines corresponding in length, breadth, and height or depth. To draw a circle isometrically some simple methods are proposed; the circle drawn isometrically appears to be expanded or contracted to an elliptical or oval-shaped form, as is at once seen by cutting a cylinder or tube at an angle of 30 degs. It has been found that after setting off and squaring up on the △ drawing-board the two diameters of a circle, they are enclosed in a lozenge or isometrical square, and that the obtuse apex of this lozenge gives the centre for the drawing of the arc of a circle corresponding to the curve of the circumference of the minor axis between the points where the diameters of the circle touch the lozenge, the radius of which is given by the distance from the outer apex to these points; and the half of the minor axis gives the radius for completing the circles from these points by describing the end curves of the major axis of the ellipse of an isometrical circle, or these curves may be drawn freely by hand or with templates. To draw any other angles more or less right angles, a lozenge-shaped protractor is proposed. In this the lozenge is divided by two diameters parallel to the sides, into four isometrical squares; of these, the outer corners are divided for the angles of 45 degs., the outer sides of these squares are divided for divisions of 15 degs. each; these again subdivided into three divisions of 5 degs. each; these again minutely divided into five equal parts, corresponding each to a degree. This protractor gives at once right and left any required angle from the centre of the diameter parallel to the sides of the lozenge. For any angle from any base line not parallel to the sides of the lozenge, it is only necessary to take a diameter of the lozenge corresponding to the base line, and the required angles are set off from the centre of that diameter right or left. It is supposed that the use of equilateral-triangular copper plates and triangular blocks of boxwood will greatly facilitate the application of isometrical drawing to copper plate and woodcut engravings.—*Architect.*

[This method was described in the American papers some four years since.—ED.]

FINISHING WOOD WITH CHARCOAL.—The "United States Cabinet Maker" gives the following brief account of the method adopted by French cabinet-makers of producing a dead black on furniture and other work:—All the world now knows of those articles of furniture of a beautiful dead black color, with sharp clear-cut edges, and a smooth surface, the wood of which seems to have the density of ebony. Viewing them side by side with furniture rendered black by paint and varnish, the difference is so sensible that the considerable margin of price separating the two kinds explains itself without need of comment. The operations are much longer and much more minute in this mode of charcoal polishing, which respect every detail of the carving, while paint and varnish would clog up the holes and widen the ridges. In the first process only carefully selected woods of a close and compact grain are employed; these are covered with a coat of camphor dissolved in water, and almost immediately afterwards with another coat composed chiefly of sulphate of iron and nut-gall. The two compositions in blending penetrate the wood and give it an indelible tinge, and at the same time render it impervious to the attacks of insects.

When these two coats are sufficiently dry, they rub the surface of the wood at first with a very hard brush of couch-grass, or dog's-tooth grass, (*Triticum repens*) and then with charcoal of a quality as light and friable as possible, because if a single hard grain remained in the charcoal this alone would scratch the surface, which they wish, on the contrary, to render perfectly smooth. The flat parts are rubbed with natural stick charcoal, the idented portions and crevices with charcoal powder. At once, almost simultaneously, and alternately with the charcoal, the workman also rubs his piece of furniture with flannel soaked in linseed oil and the essence of turpentine. These pouncings, repeated several times, cause the charcoal powder and the oil to penetrate into the wood, giving the article of furniture a beautiful color and perfect polish, which has none of the flaws of ordinary varnish. Black wood, polished with charcoal is coming day by day to be in greater demand; it is most serviceable; it does not tarnish like gilding, nor grow yellow like white wood, and in furnishing a drawing-room it agrees very happily with gilt, bronzes, and rich stuffs. In the dining-room, too, it is thoroughly in its place to show off the plate to the greatest advantage, and in the library it supplies a capital frame-work for handsomely bound books.—*English Mechanic.*

THE largest crane in the world has just been erected at the docks at Barrow-in-Furness, by Sir W. G. Armstrong and Co., Newcastle-on-Tyne. It lifted 100 tons of rails with ease last September at the experimental trial.